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SAMPLE ABSTRACT & INFORMATION FORM

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MICROBIAL ACTIVITY IN THE DIGESTIVE TRACT OF THE HALFMOON, *Medialuna californiensis*. J. S. Kandel¹, J. R. Paterek² and M. H. Horn¹. ¹California State Univ. Fullerton, CA 92634 and ²Agouron Institute, La Jolla, CA 92037.

We report the presence of a diverse microbial flora and of microbial fermentation products in the hindgut region of the halfmoon, *Medialuna californiensis*, a seaweed-eating fish from southern California coastal waters. Viable aerobic and anaerobic bacteria were found in all sections of the gut, but were of highest concentration (10^5 – 10^8 /ml) in the hindgut. Microscopy revealed vibrios, spirilla, rod-shaped bacteria and flagellated protozoa in the midgut and hindgut, but primarily vibrios and rods in the stomach and foregut. Acetic, isobutyric and butyric acids, the volatile products of microbial breakdown of carbohydrates, were found only in the hindgut, as was ethanol, a nonvolatile product. These results provide the first evidence for microbial fermentation and its possible contribution to the energy supply in a north-temperate herbivorous fish.

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Recruitment, Growth, and Survivorship of Black Abalone on Santa Cruz Island following Mass Mortality

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Abstract.—Populations of black abalone experienced major declines in abundance throughout the California Channel Islands in the late 1980's. The focus of this research was to monitor the potential recovery of populations on Santa Cruz Island in 1990–1993 following mass mortality in 1987–1989. Abalone continued to decline in abundance between 1990–1993. These declines were associated with low survivorship and low relative weights, indicating that individuals were continuing to die from the withering syndrome (WS) which was associated with the principal mass mortality. Recruitment, and the movement of small abalone from their cryptic juvenile habitat unto open surge channels, was an important process maintaining adult abundance. However, major declines in the density of juvenile abalone occurred between 1991–1993. Small abalone (<70 mm in length) exhibited the greatest effects of WS and these effects decreased with increasing size. Temperature was indicated to be the single most important factor influencing population recovery. Oceanographic factors that result in elevated seawater temperatures, such as El Niño, will have a strong negative impact on the recovery of black abalone populations in southern California.

Prior to the mid-1980's populations of black abalone, *Haliotis cracheroidii*, occurred at extremely high densities ($\approx 50\text{--}75\text{ m}^2$) throughout the California Channel Islands (Bergen 1971; Douros 1985, 1987). Shortly thereafter, populations on most of the islands began dramatic declines in abundance, often exceeding 90% (Davis et al. 1992; Haaker et al. 1992; Tissot 1988a). This precipitous decline, or mass mortality, occurred in conjunction with the "withering syndrome" (WS): abalone were shrunken in appearance, weakly attached to the substratum, and did not actively feed (Tissot 1991). At present the ultimate causes of the mortality are unclear, but possible factors include the effects of elevated temperatures, fluctuations in the abundance of drift algal foods, high abalone densities, and the spread of a pathogen (Culver and Richards 1992; Davis et al. 1992; Haaker et al. 1992; Lafferty and Kuris 1993; Steinbeck et al. 1992; Tissot 1991).

The focus of this research is to monitor changes, and potential recovery, of populations on Santa Cruz Island in 1990–1993 following major declines in 1987–1989 (Tissot 1991). I address the following questions:

- Did populations display any indication of recovery?
- Did WS continue to occur and did it influence survivorship?
- Was recruitment occurring and did it influence abundance?

I addressed these questions by monitoring the growth and survivorship of tagged abalone located along permanent transects established in 1987. Recruitment was monitored by surveying the abundance of juvenile black abalone, which primarily occur under rocks in boulder fields (Tissot 1988b).

Materials and Methods

Study sites were located on the west end of Santa Cruz Island (34°00'N, 114°50'W), California. Intertidal transects were located in two general areas that differed in their exposure to ocean waves. The "wave-protected" site (hereafter referred to as "protected") was located 1 km SE of Forney Cove on the south side of the island. The "wave-exposed" site (hereafter referred to as "exposed") was located 0.2 km NE of Fraser Point on the north side of the island (see Tissot 1991).

In 1987, I established 3–4 permanent intertidal transects in surge channels at each study site. In 1990 I established 2 additional permanent transects in a boulder field at the protected site. Surge channel transects were 1 m wide and 5–15 m long; boulder field transects were 4 m wide and 25 m long. Transects were oriented perpendicular to the shore and extended from the mid- to the low-intertidal zones. I conducted surveys on a quarterly basis (winter, spring, summer, fall) between January 1987 and January 1990, and on an annual basis during the summer between 1990 and 1993.

I determined abalone abundance on each transect by counting the total number of individuals present. Density was calculated by dividing the total number of individuals by the total transect area after removing areas that were deemed uninhabitable by abalone. In 1990, I began measuring the shell length of all individuals on transects.

During surveys I tagged 5–75 haphazardly chosen abalone on, or adjacent to, each surge channel transect. Abalone were removed from the substratum using an abalone iron, their shells were cleaned with a wire brush, and they were tagged with an identifying number from a Dymo label maker applied to the shell with marine epoxy putty (Z-spar Splash Zone Compound). Damage to the foot resulting from handling was noted. Statistical comparisons between damaged and undamaged abalone revealed no significant differences in survivorship, rates of shell growth, weight gain, or net total movement (T-test, all $P > 0.05$). For each individual I measured the length of the shell in the longest dimension with a caliper, and beginning in June 1988, the total wet abalone weight after the removal of shell growths, with a spring scale. Individuals that were abnormally underweight in appearance were noted.

Survivorship was measured by the recapture rate of tagged individuals. In order to make valid comparisons among survey intervals, which varied in duration, I calculated all recapture rates based on annual survivorship (e.g., summer 1987 to summer 1988).

I calculated shell growth as the change in length per unit time (mm/month). I derived an index of abalone "condition" using total abalone weight, hereafter referred to as "relative weight." Relative weight was calculated by measuring the percent deviation of abalone weight from a predicted weight, which was based on a logged length-weight regression calculated from field recaptured individuals

displaying both shell growth and increases in total weight between surveys in 1988–1990:

$$\text{Log}_e \text{predicted weight} = -9.36 + 3.15 \times \text{Log}_e \text{length}$$

($r^2 = 0.97$, $N = 87$, $P < 0.01$). Relative weight was then calculated as a percent deviation from predicted weight:

$$\text{Relative weight} = \frac{\text{Weight} - \text{Predicted weight}}{\text{Weight}} \times 100$$

Although the calculation of a relative weight index using growing individuals as a standard was somewhat arbitrary, it served as a standard by which to make weight comparisons among years. Of the 49 individuals that were observed to be abnormally underweight during surveys, 88% ($N = 43$) of their calculated relative weights were < 0 (the mean of “growing” individuals). Hence the method probably underrepresented the extent of withered abalone. Furthermore, since relative weights were based on total animal weight (shell + soft parts), the extent of shrunken soft parts was further underestimated. For example, based on measurements of 97 individuals from Santa Cruz Island the soft parts account for an average of 48.6% of the total weight (Tissot, unpublished data). Therefore, an abalone with a relative weight of -10% actually had soft parts (foot + viscera) that were 20.6% below their predicted weight.

I obtained monthly surface seawater temperatures for the general area of Santa Cruz Island using satellite imagery data (NOAA 1987–1993). These temperatures were consistent ($\pm 1.0^\circ\text{C}$) with values taken intertidally during surveys. Mean monthly temperatures were extracted for the years 1987–1993 and compared to average annual surface values derived for the Santa Cruz Island area for 1942–1969 from Robinson (1976). I calculated the annual temperature anomaly as the mean difference between actual monthly temperatures and average monthly temperatures from Robinson (1976).

Results

Abalone density on surge channel transects exhibited a net decline throughout the 1987–1993 study period (Fig. 1A). Transects along the protected coast declined from a mean density of $\approx 60/\text{m}^2$ in 1987 to less than $1/\text{m}^2$ in 1993. Similarly, along exposed coasts, density declined from $\approx 45/\text{m}^2$ to less than $1/\text{m}^2$. Rate of change in density was greatest between 1987–1988 surveys (Fig. 1B). There were small increases in abundance between surveys in 1989 in both study areas and between the 1990–1991 survey on the exposed coast, but further declines occurred between 1991–1993. The rate of decline of abalone density did not differ among transects (comparison among slopes: $F = 0.67$; $df = 7, 109$; $P > 0.05$) indicating that declines were not related to initial abalone density.

Patterns of variation in abalone size differed among exposed and protected surge channel transects (Fig. 2). Individuals < 80 mm and > 100 mm decreased in abundance and eventually disappeared along exposed coast transects between 1990–1992. In contrast, the relative proportion of individuals < 40 mm increased and individuals > 100 mm decreased along protected coast transects during the same time period. There was a significant negative correlation between the mean

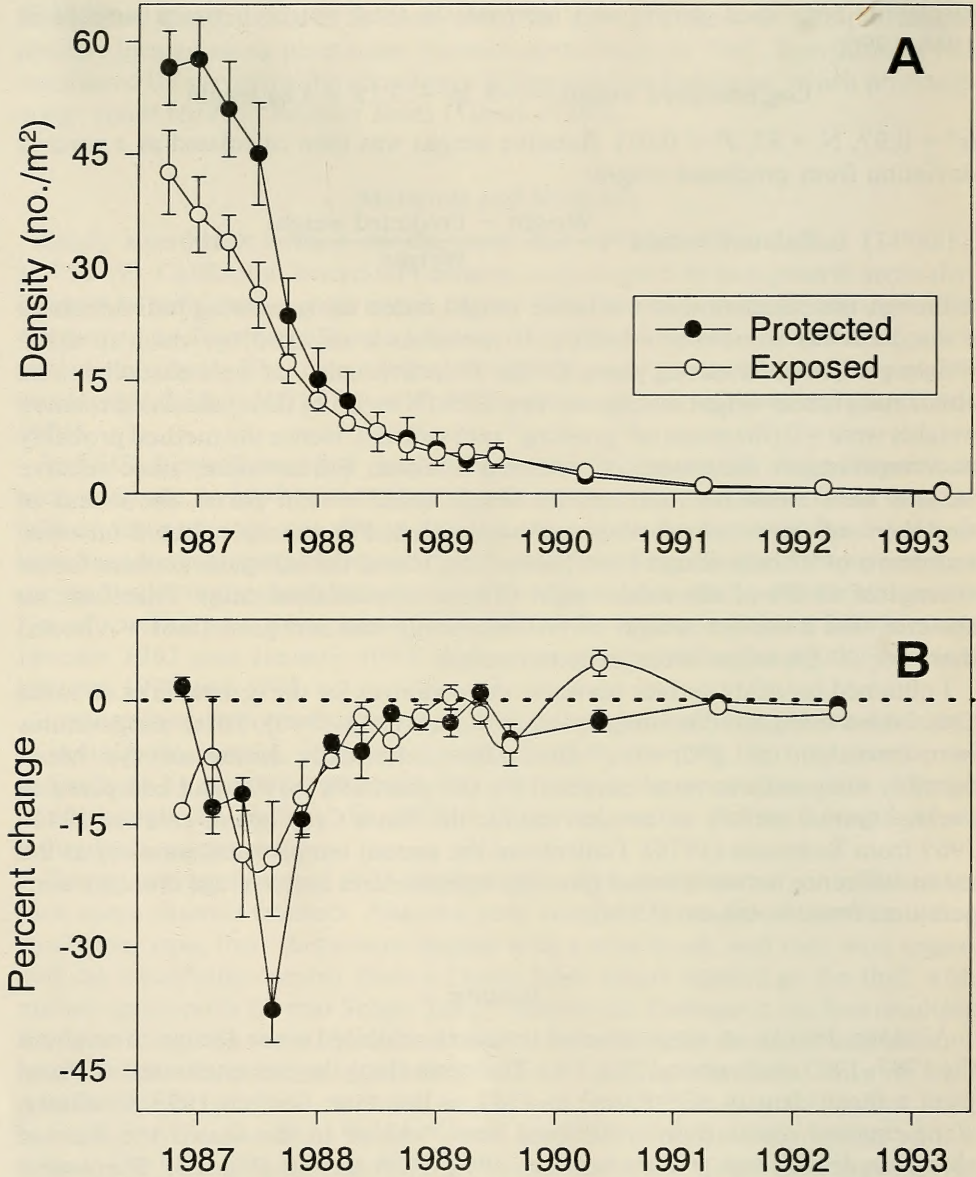


Fig. 1. Patterns of decline in abundance, 1987–1993. A. Mean density (± 1 S.E.) on exposed vs. protected study areas. B. Percent change in mean density (± 1 S.E.) relative to initial densities on exposed vs. protected study areas.

size of abalone on transects in 1990–1993 and their 1993 density ($r = -0.62$, $N = 8$, $P < 0.05$), indicating that sites where abalone were relatively more abundant were composed primarily of small individuals.

Individuals on boulder field transects exhibited significant variation in size and density among years (Fig. 3). There were major declines in the density of all size classes between 1991 and 1992–1993. Total mean density varied from a high of $1.4/\text{m}^2$ in 1991 to a low of $0.51/\text{m}^2$ in 1993.

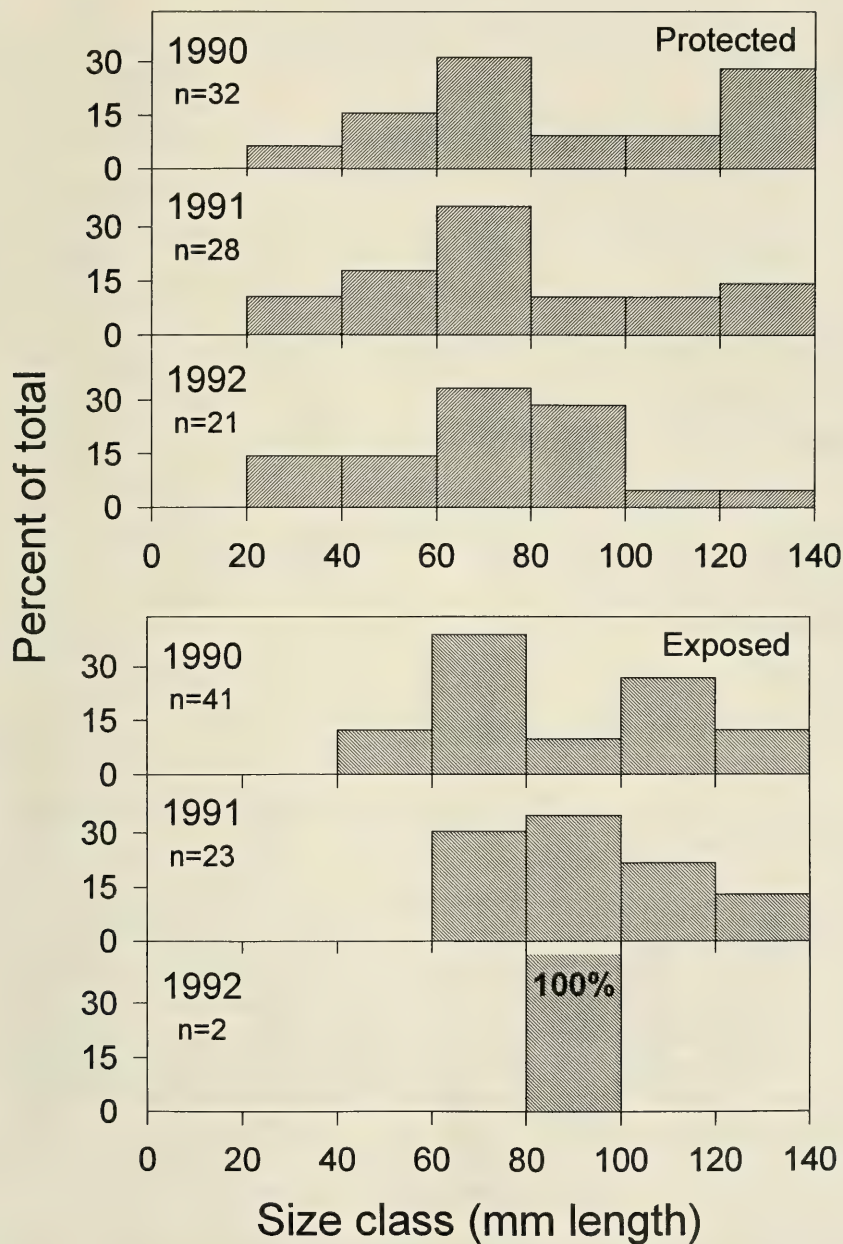


Fig. 2. Size frequency of abalone on surge channel transects in exposed and protected study areas (N = sample size).

Annual survivorship, as measured by the recapture rate of tagged abalone on surge channel transects, was significantly different among surveys (Kruskal-Wallis, $H = 11.96$, $N = 24$, $df = 5$, $P < 0.05$) (Fig. 4A). Recapture rates averaged 8% between summer surveys in 1987–1991 and 1992–1993, which were not significantly different from each other, and 31% between the 1991–1992 surveys (Tukey's test, $P < 0.01$).

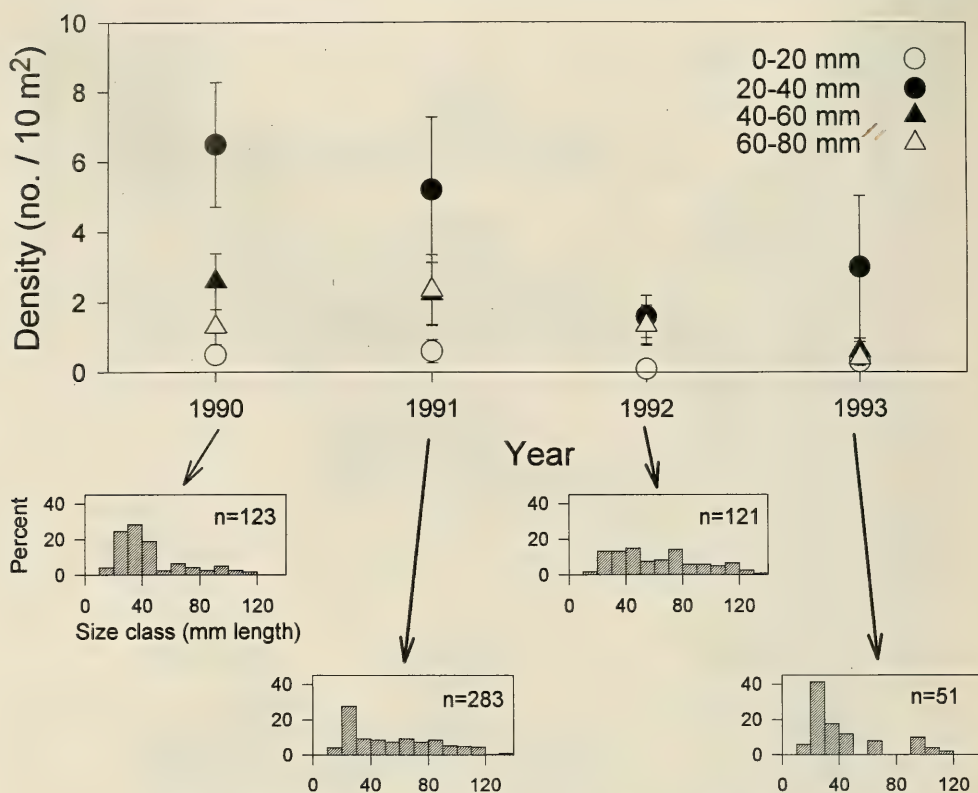


Fig. 3. Changes in mean density (± 1 S.E.) of four size classes and size frequency of abalone on boulder fields (N = sample size).

The relative weight of individuals fluctuated during the study period (Fig. 4B). Mean weights were significantly different among years (Kruskal-Wallis, $H = 39.5$, $N = 405$, $df = 5$, $P < 0.01$): 1989 weights, which averaged 6.3% above predicted weight, were significantly different from all other years, which averaged 4.0% below predicted weight (Tukey's test, $P < 0.01$). Mean relative weight of abalone ≤ 70 mm, which averaged 8.1% below predicted weight, was significantly different from abalone > 70 mm, which averaged 1.5% below predicted weight (T-test, $T = 2.93$, $df = 192$, $P < 0.01$).

Shell growth rates also exhibited high variability among years (Fig. 4C), however, there were no significant differences among years (Kruskal-Wallis, $H = 4.71$, $N = 59$, $df = 4$, $P > 0.05$).

Surface seawater temperatures were elevated above normal levels during all years of the study (Fig. 5). Average annual temperature anomalies were significantly different among years (Kruskal-Wallis, $H = 24.5$, $N = 84$, $df = 6$, $P < 0.01$) and varied from a mean of 1.2°C above average for 1987, 1988, 1990, 1992 and 1993, which were not significantly different from each other, to a mean of 0.41°C above average in 1989 and 1991 (Tukey's test, all $P < 0.01$). Mean relative weights were significantly negatively correlated with mean winter temperature anomalies in 1987–1992 ($r = -0.88$, $N = 6$, $P < 0.01$), but not with mean spring, summer, or fall temperature anomalies (all $P > 0.05$).

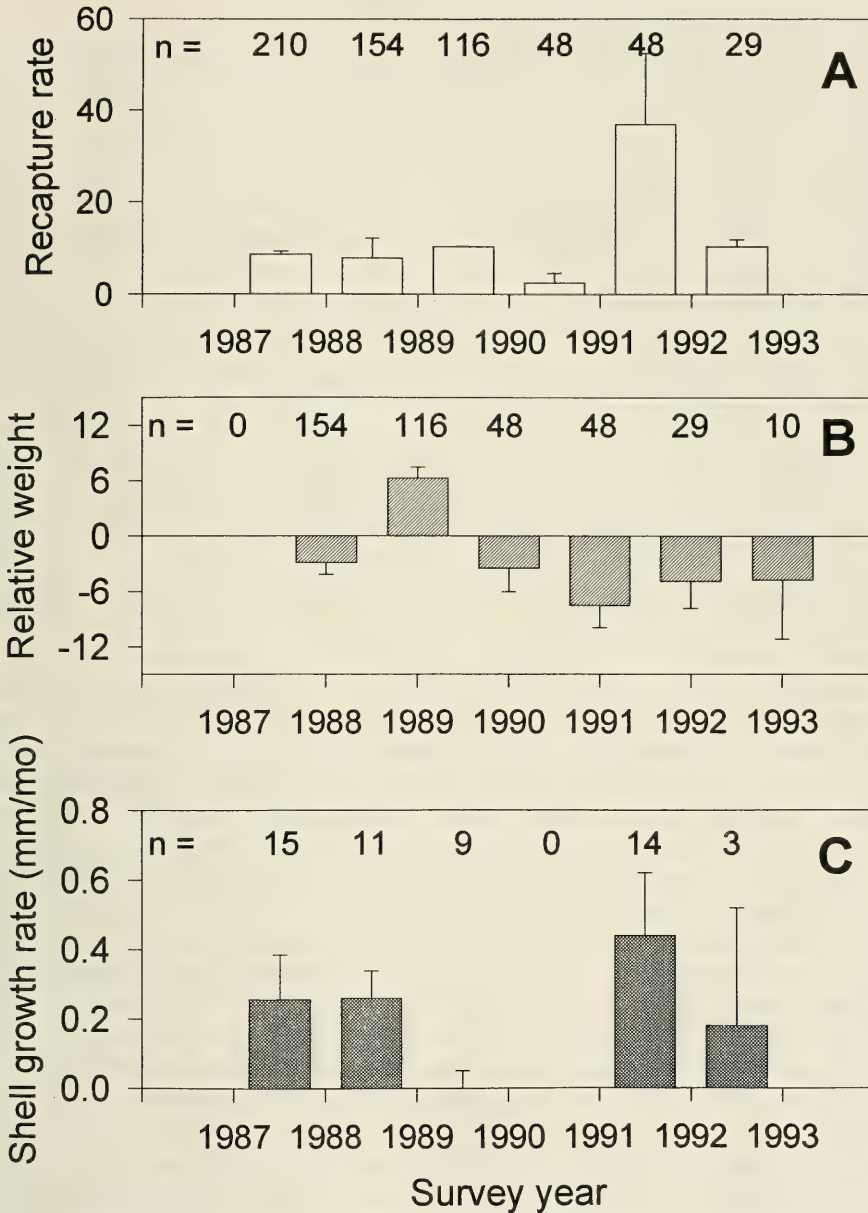


Fig. 4. Patterns of variation in growth and survivorship of tagged abalone (N = sample size). A. Mean recapture rate (± 1 S.E.). B. Mean relative weight (± 1 S.E.) (see text). C. Mean shell growth rates (± 1 S.E.).

Discussion

Black abalone on Santa Cruz Island exhibited a net decline in abundance throughout the seven-year study period. Annual survivorship of tagged individuals, which averaged 8% in all years except 1991–1992, were low compared to other studies. Mean annual survivorship of ten species of abalone ranged from 0–92% but averaged 39% (Shepherd and Breen 1992). A better comparison can

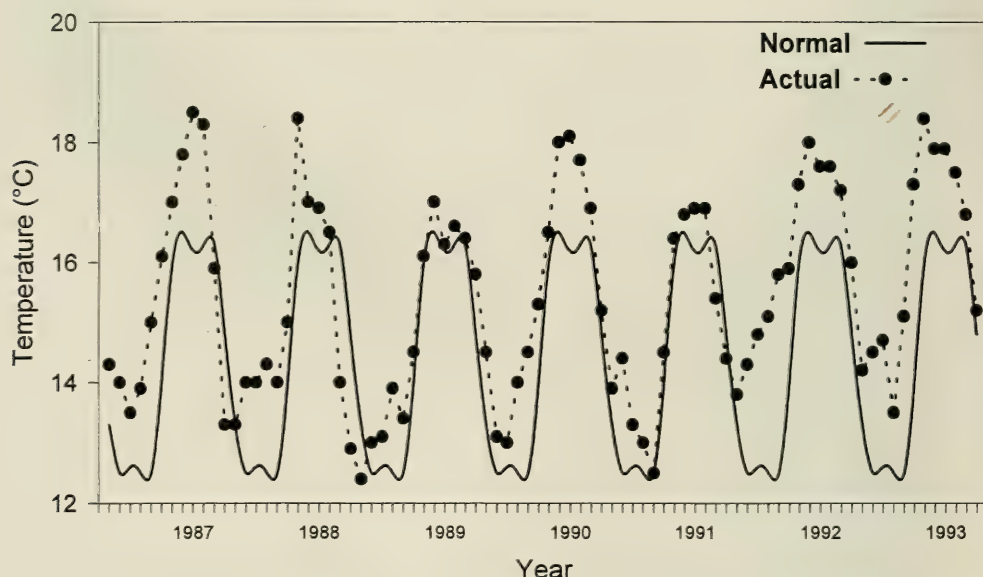


Fig. 5. Relationship between monthly seawater temperatures during the study period and average annual temperatures based on Robinson (1976).

be made using tagged black abalone on Año Nuevo Island in central California during 1987–1990 which did not exhibit WS, where annual survivorship averaged 33% (Tissot, unpublished data). In conjunction with low survivorship, relative abalone weights at Santa Cruz Island averaged 4.0% below predicted in all years except 1989. In contrast, using the same methodology to calculate relative weight at Año Nuevo Island, mean relative weights averaged 1.9% above predicted in 1988–1990. Thus population declines on Santa Cruz Island occurred in conjunction with low survivorship and low relative weights, indicating that elevated mortality rates continued to be associated with the withering syndrome. Important issues to be addressed are the effects of WS on the decline and recovery of the population and the role of ecological factors, such as seawater temperature, kelp abundance, and recruitment as they influence growth and survivorship.

The abundance of abalone on surge channel transects exhibited major declines between 1987 and 1993. Tissot (1991) has shown that these declines were primarily associated with mortality and not from handling injury, human disturbance, or emigration from study areas. Overall, the total decline between 1987 and 1993 has been 99.5%. In 1987 there were a total of 2630 abalone on all transects; 14 remained in 1993. Abundance has been reduced to zero on two of the eight transects, one each in exposed and protected study areas. If the current rate of decline continues, black abalone will be locally extinct on my study areas by 1997 (± 2 years).

There was a strong relationship between the persistence of abalone on surge channel transects and their size composition. Study areas on the protected coast with the highest densities in 1993 exhibiting an influx of small abalone < 40 mm into the study area. In contrast, lower density transects on the exposed coast were associated with an absence of small abalone. These observations indicate that recruitment, and the movement of small abalone from their cryptic juvenile

habitat into open surge channels, is an important process maintaining adult abundance. Similar observations have been made by Blecha et al. (1992) in central California. Boulder habitats suitable for small abalone are uncommon on the exposed coast of west Santa Cruz Island but are abundant on the protected coast. Therefore, a prediction from this study is: should abalone recovery occur in southern California, it will be higher in areas adjacent to intertidal boulder fields.

Newly recruiting and juvenile abalone in boulder fields exhibited high variation in abundance during 1990–1993. Declines in the density of all size classes occurred between 1991–1993 during abnormally warm temperatures associated with the 1992–1993 El Niño. There are at least two ways El Niño could have a negative effect on abalone recruitment and juvenile survivorship. First, ocean currents in southern California generally flow to the north during El Niño, transporting pelagic larvae from south to north (Cowen 1985). Because black abalone populations were decimated by mass mortality throughout southern California (Culver and Richards 1992), a northern flowing current might be sparsely laden with abalone larvae. In contrast, under normal oceanographic conditions, southern flowing currents would transport abalone larvae south from central California, where abalone are still abundant (Tissot 1991). A second mechanism is that elevated temperatures during El Niño enhance the effects of withering syndrome on juvenile abalone, resulting in elevated mortality.

Tissot (1991) demonstrated a strong relationship between the survivorship of tagged abalone and their relative weight, which thus served as a measure of the severity of WS. In this study relative weights of abalone were similar in 1990–1993 to those in 1988, when major mortality occurred. These observations demonstrate that WS has been present throughout the seven-year study period and associated with the continued high mortality. Perhaps more importantly, relative weight was strongly size dependent. Abalone <70 mm in length exhibited the greatest effects of WS and these effects decreased with increasing size. Thus, the continued presence of WS is having two major impacts on the populations: 1) low survivorship of adults; and 2) low survivorship of recruiting abalone which maintain adult populations.

Previous work by Steinbeck et al. (1992) and Tissot (1991) has shown temperature to have a strong effect on the incidence and severity of WS and resulting survivorship. Similar strong relationships between temperature, WS, and survivorship were evident in this study. Relative weights and survivorship were low during warm years in 1988, 1990, and 1992 but increased during oceanographically more normal years in 1989 and 1991. Moreover, low abalone weights were significantly correlated with elevated seawater temperatures during the winter season. Because black abalone store excess energy in the form of polysaccharides in the foot during the winter (Webber and Giese 1969), abalone mortality may be occurring due to a disruption of energy storage. Although the abundance of drift kelp, the principal food of black abalone, was unusually low during 1987–1988 during peak population declines (Tissot 1991), it did not appear to exhibit significant variation between 1989–1993, and thus was unlikely to be the continued cause of WS (Tissot, unpublished data). Therefore, temperature is the single most important factor influencing population recovery. Oceanographic factors that result in elevated seawater temperatures, such as El Niño, will have a strong negative impact on the recovery of black abalone populations.

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Distribution of Brittlestar *Amphiodia* (*Amphispina*) spp. in the Southern California Bight in 1956 to 1959

Mary Bergen

Southern California Coastal Water Research Project, 7171 Fenwick Lane,
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Abstract.—Brittlestars *Amphiodia* (*Amphispina*) spp., particularly *Amphiodia* (*Amphispina*) *urtica* (Lyman 1860), are of interest in southern California because they are rare or absent adjacent to municipal wastewater outfalls even where they are expected to be the community dominant. In the monitoring programs for the outfalls, impacts to benthic communities are determined by comparing abundances near the outfall to the abundance in "reference" areas. In order help define reference conditions, data from a survey conducted between 1956 and 1959 were used to determine the effect of latitude, depth and sediment grain size on the distribution and abundance of *Amphiodia* (*Amphispina*) spp.

Brittlestars *Amphiodia* (*Amphispina*) spp. were most abundant in water depths of 48 to 102 m in sediments with median grain size between 0.035 and 0.093 mm, a diameter classified as coarse silt to very fine sand. *Amphiodia* (*Amphispina*) spp. were rarely collected in less than 15 or more than 85 m of water.

The abundance of *Amphiodia* (*Amphispina*) spp. was generally lower north of Ventura than elsewhere in the Bight. The difference in abundance can, in part, be attributed to the character of the sediment. However, even in areas with suitable sediment, the abundance of *Amphiodia* (*Amphispina*) spp. north of Ventura was relatively low. The reason for this difference is unknown. It is also not known if *Amphiodia* (*Amphispina*) spp. are, at the present time, less abundant north of Ventura than elsewhere in the Bight.

The brittlestar *Amphiodia urtica* (Lyman 1860) has become a subject of study in recent years because it is rare or absent in areas adjacent to municipal wastewater outfalls in southern California even where it is the expected community dominant (County Sanitation Districts of Orange County 1990; City of Los Angeles 1990; City of San Diego 1990). For this reason, it has been used as an indicator organism in monitoring programs. In these programs alterations in benthic communities are determined by comparing areas adjacent to the outfall areas to "reference" areas. However, there has been some dispute as to what constitutes an appropriate reference area.

The objective of this study was to use the data from an extensive oceanographic, geological and biological survey of the southern California Bight (hereinafter called the State survey) to help determine reference conditions for *Amphiodia urtica*. More specifically, the objective was to determine the effect of latitude, depth, and sediment grain size on the abundance of *Amphiodia urtica* in the Bight.

The State survey was conducted between 1956 and 1959 by scientists of the Allan Hancock Foundation, under contract to the State Water Pollution Control

Board. For the first six months, the objective of the survey was to provide descriptive information about the Bight. During this period, stations were randomly chosen within a systematic grid pattern. Then the sample design was changed in order to assess the effect of waste discharges and to determine seasonality in benthic invertebrate populations. The mainland shelf was divided into 15 geographic zones, each classified according to present and possible future effects of wastewater discharges. Transects with three to six stations were established in each zone. To measure seasonality, stations were to be sampled two or more times per year.

This sample design was, however, abandoned because it was not possible to determine seasonality or the effect of the discharges given the variability caused by such factors as substrate type and navigational error. Therefore, a stratified design was adopted, in which the Bight was divided into eight geographic zones, each with six depth zones. This design assured good spatial coverage of the Bight.

In the end, samples were, more or less, evenly distributed throughout the Bight. From Point Arguello to 4 km south of the Mexican Border, hydrographic information was collected at 2582 stations; 862 biological and 900 sediment samples were collected (Jones 1969). To date, this is the only truly Bight-wide survey that has been done. The analyses of macroinvertebrate distributions and descriptions of infaunal communities which appeared in reports for the project (Allan Hancock Foundation 1959, 1965; Stevenson 1961) and in published papers (Barnard and Hartman 1959; Barnard and Ziesenhenné 1960; Jones 1969) form the foundation of our knowledge of the benthos of the Bight.

While previous reports based on the State survey data discussed the distribution of *Amphiodia urtica*, they did not specifically focus on *Amphiodia*; nor did they use all available data. For instance, the description of ophiuroid communities by Barnard and Ziesenhenné (1960) was based on data from 176 samples, supplemented by visual inspection of an additional 400 samples for faunal dominance. However, all organisms were identified in 322 samples and all echinoderms were identified in 240 samples. Therefore, there are potentially 562 samples that can be used to delimit the distribution of *Amphiodia urtica*.

As discussed below, examination of specimens suggest that, during the State survey, there was some confusion in the identification of *Amphiodia urtica* and a closely related species, *Amphiodia digitata* Nielson, 1932. For this reason, data for the two species were combined under the subgeneric designation *Amphiodia (Amphisipina)* spp. Even though this designation is used, over 80% of the specimens were *Amphiodia urtica*.

Methods

In the State survey, most of the benthic samples were taken with a Hayward Orange Peel Grab with a rated capacity of 56.6 l, sampling a surface of approximately 0.25 m². A modified Van Veen grab was used to sample areas in less than 10 m of water. This grab has a capacity of two liters and samples 0.1 m². A Campbell grab was used on three occasions; however, data from these samples were not used in the analysis.

Samples taken with the Orange Peel grab were screened through 1.0 mm mesh in the field, preserved in 10% formalin and transported to the laboratory for

sorting and identification. Sediment taken with the Van Veen was preserved and taken to the laboratory for screening, sorting and identification.

Prior to screening, approximately 0.5 l of sediment was taken from the grab for sediment grain size analysis. These samples were not refrigerated or preserved. They often dried before analysis. Before processing, the sample was soaked in water and then wet-sieved through 0.062 mm mesh screen to remove the gravel and sand fraction. The percent sand and gravel was determined by settling (Emery 1938). The silt/clay fraction was washed in acetone and filtered several times to remove salts and organic matter. The percent silt and clay was determined by pipette analysis (Rittenhouse 1939). The median grain size diameter was calculated by the method of Trask (in Krumbein and Pettijohn 1938).

The echinoderms taken in the State survey were identified by Fred Ziesenhenné, a taxonomist with the Allan Hancock Foundation. Mr. Ziesenhenné published a number of papers on echinoderms, including descriptions of species. To verify the quality of the taxonomy, Dr. Gordon Hendler of the Los Angeles County Museum of Natural History checked the identifications in approximately 17 samples. He found that most specimens were *Amphiodia urtica*, as identified. However, there was some confusion in the identification of a closely related species, *Amphiodia digitata* Nielson 1932. In addition, many specimens identified as *Amphipholis squamata* (delle Chiaje 1828) were juvenile *Amphiodia urtica*. Since 80% of all the ophiuroids collected were identified as *Amphiodia urtica* and only 1% were identified as *Amphiodia digitata*, this taxonomic confusion does not materially affect the data. However, to resolve the taxonomic uncertainty, the data for *A. urtica* and *A. digitata* were combined under the designation *Amphiodia* (*Amphispina*) spp. Other species of *Amphiodia*, including *A. occidentalis* and *A. psara*, were collected during the survey. However, these species lack the points on the ventral scales that are characteristic of the subgenus *Amphispina*. Thus the designation *Amphiodia* (*Amphispina*) spp. serves to distinguish *A. urtica*/*A. digitata* from other species of *Amphiodia* collected in the survey. Specimens identified as *Amphipholis squamata* were not included in the data because it was not possible to determine which specimens had been misidentified. Thus the numbers for *Amphiodia urtica* are probably underestimated; however, since only 10% of all ophiuroids collected were identified as *Amphipholis squamata*, the magnitude of the underestimate is small.

All echinoderms were sorted and identified in 562 samples; 537 of the 562 samples were used in the following analyses (Fig. 1). 457 of 537 samples were taken with an Orange Peel grab (OPG); 96 samples were taken with a Van Veen grab. The other samples were excluded either because no sample volume was recorded (16 samples), there was uncertainty about the taxonomy (six samples), or the samples were taken with a Campbell grab (three samples).

In order to make data from samples taken with an OPG and a Van Veen roughly comparable, the number of animals per grab was converted to number per m². Since the area sampled by the Van Veen is 0.1 m² regardless of the depth of penetration of the grab, the conversion simply involves multiplying the number of animals per grab by ten. However, with the OPG, the area sampled varies with the depth of penetration of the grab up to the maximum gape of the jaws. During the State survey, a field test was run in order to determine the relationship between sample volume and surface area sampled (Jones 1961). The results are as follows:

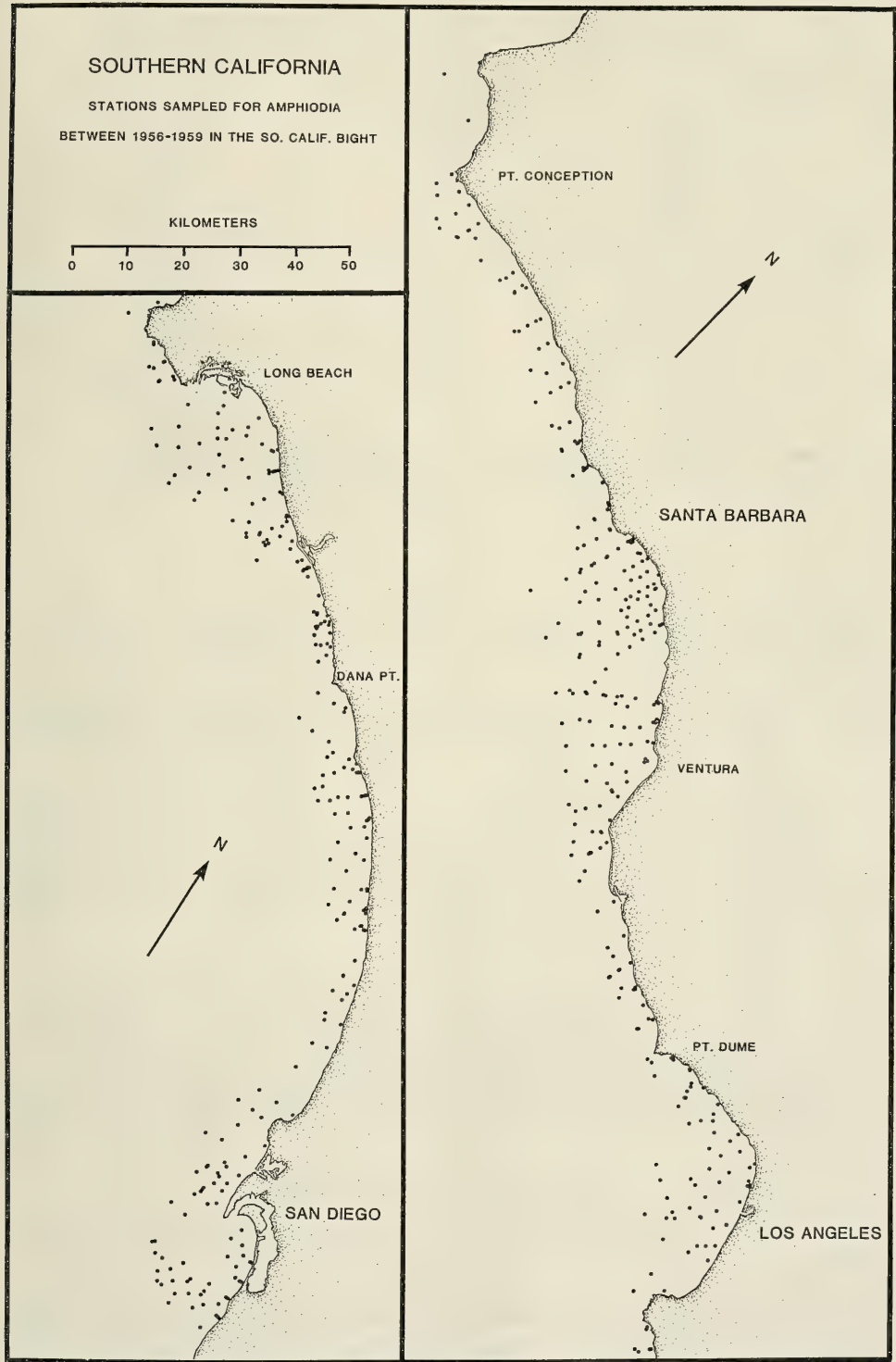


Fig. 1. Chart showing location of samples used in the analyses in this report.

Volume of Grab (ft ³)	Area (m ²)	Conversion Factor (for number/m ²)
1.5	0.25	4
1.0	0.20	5
0.75	0.17	6
0.50	0.15	7
0.25	0.135	8

For this study, the conversion factor was formularized as follows:

$$\text{If } V < 1, \quad CV = 8 - (4*(V - 0.25))$$

$$\text{If } V \geq 1 \leq 1.5, \quad CV = 5 - (2*(V - 1.0))$$

$$\text{If } V > 1.5, \quad CV = 4$$

where

V = volume of the grab

CV = conversion factor.

Results

The range in median grain size in samples with more than 1500 *Amphiodia* (*Amphispina*) spp. per square meter was 0.035 to 0.093 mm (Fig. 2), a diameter which is classified as coarse silt to very fine sand. If the one outlying sample with median grain size 0.093 mm is excluded, the range in median grain size in samples with more than 1500 *Amphiodia* (*Amphispina*) spp. per square meter was 0.035 to 0.073 mm. *Amphiodia* (*Amphispina*) spp. were less abundant in sediments with smaller or larger median diameters.

The depth range for samples with more than 1500 *Amphiodia* (*Amphispina*) spp. per square meter was 48 to 102 m (Fig. 3). The maximum abundance of *Amphiodia* (*Amphispina*) spp. generally decreased outside of this depth range. *Amphiodia* (*Amphispina*) spp. were rarely collected in samples taken in less than 15 or in more than 185 m of water.

Since grain size is generally correlated with depth, it is possible that the relationship between depth and abundance of *Amphiodia* (*Amphispina*) spp. is secondary, that is, the relationship is caused by the change in sediment texture rather than by depth. However, when median grain size is plotted against depth (Fig. 4), it is clear that samples with median grain size between 0.035 and 0.073 mm were taken at all depths. When the plot of *Amphiodia* (*Amphispina*) spp. abundance versus depth for samples with median grain size between 0.035 and 0.073 mm (Fig. 5) is compared to the plot of *Amphiodia* (*Amphispina*) spp. abundance versus depth for all samples (Fig. 3), the pattern is similar.

A box plot of median abundance of *Amphiodia* (*Amphispina*) spp. in 50-km sections of the coast is shown in Fig. 6. *Amphiodia* (*Amphispina*) spp. were, on the whole, less abundant in San Pedro Bay and between Ventura and Point Conception than elsewhere in the Bight. It is possible that the geographical pattern in abundance is caused by differences in distribution of sediment types. However, when the geographical pattern in sediment grain size is considered (Fig. 7), it is clear that the sediment in San Pedro Bay is similar to sediment found in other

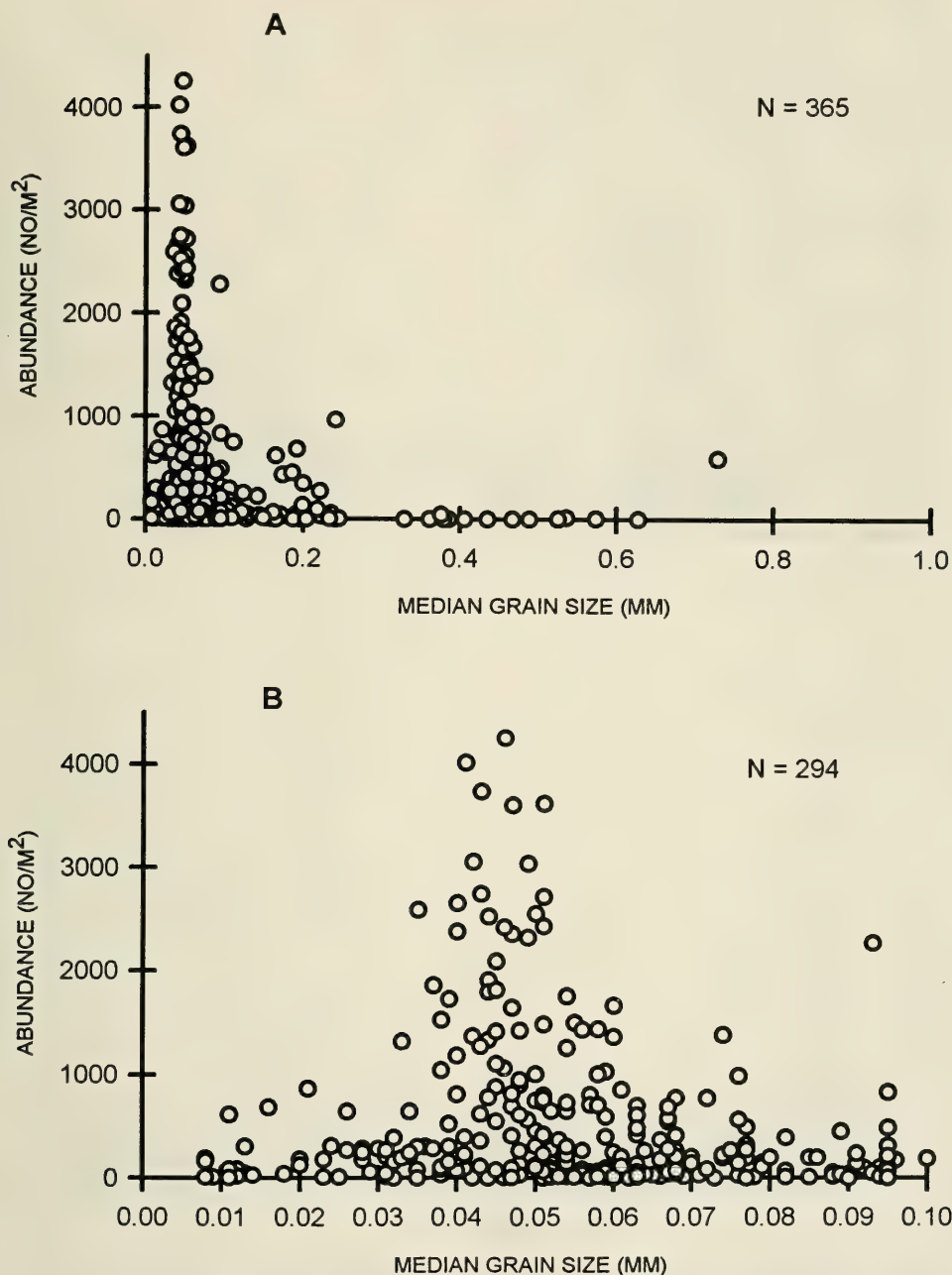


Fig. 2. Abundance of *Amphiodia (Amphisipina)* spp. vs. median grain size. An expanded view of the data for samples with median grain size < 0.10 mm is shown in Part B.

areas of the Bight. The sediment just north of Ventura is slightly finer and the sediment just south of Point Conception is slightly coarser than elsewhere in the Bight. However, the sediment off of Santa Barbara is similar to that found in San Pedro Bay and other areas of the Bight. When the distribution in abundance of *Amphiodia (Amphisipina)* spp. in samples with median grain size between 0.035

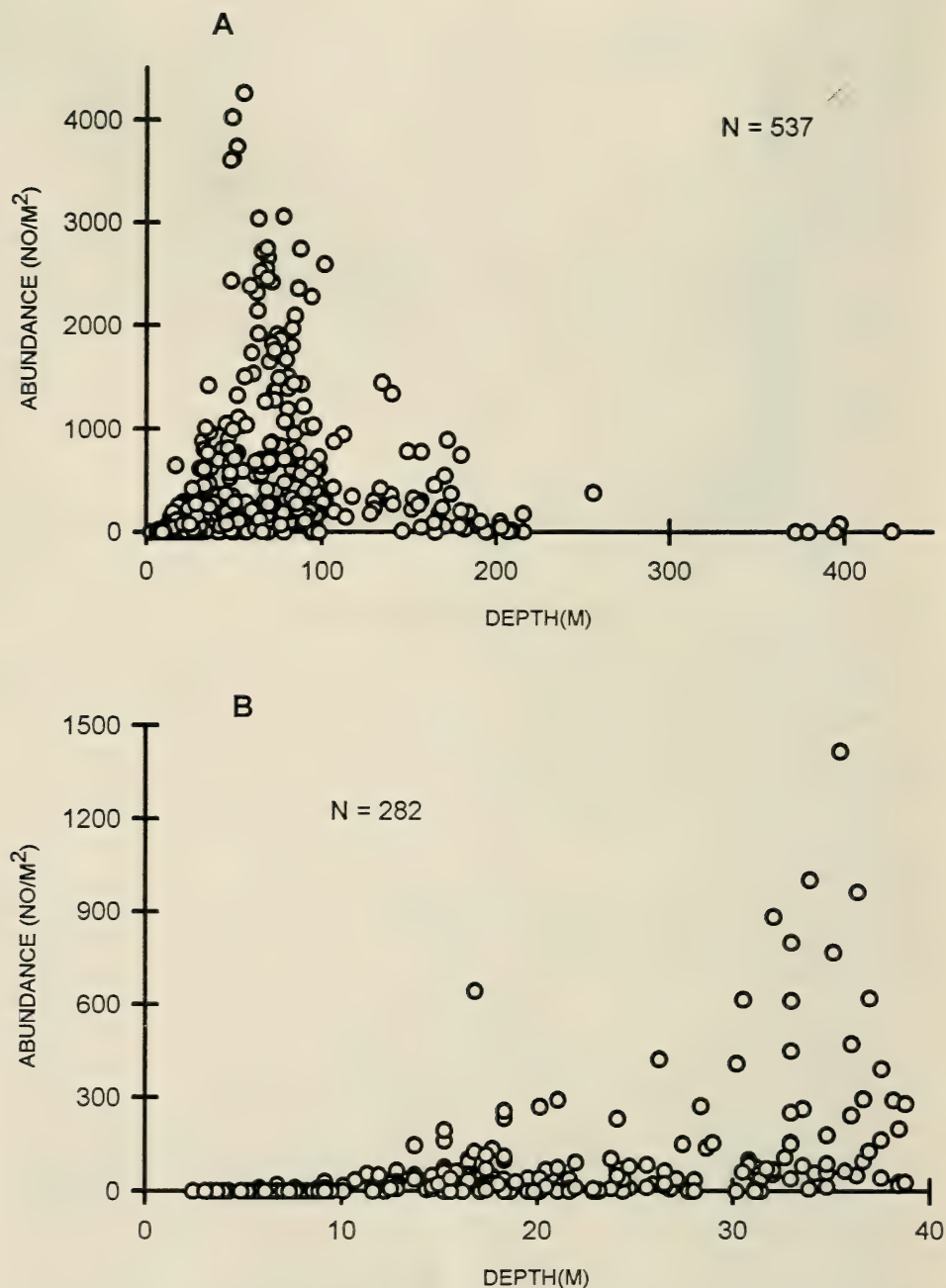


Fig. 3. Abundance of *Amphiodia (Amphispha)* spp. vs. depth. An expanded view of the data for samples taken in less than 40 m of water is shown in Part B.

and 0.73 mm (Fig. 8) is compared to the distribution of *Amphiodia (Amphispha)* spp. in all the samples (Fig. 6), the pattern is similar; that is, *Amphiodia (Amphispha)* spp. were less abundant north of Ventura and in San Pedro Bay than elsewhere in the Bight.

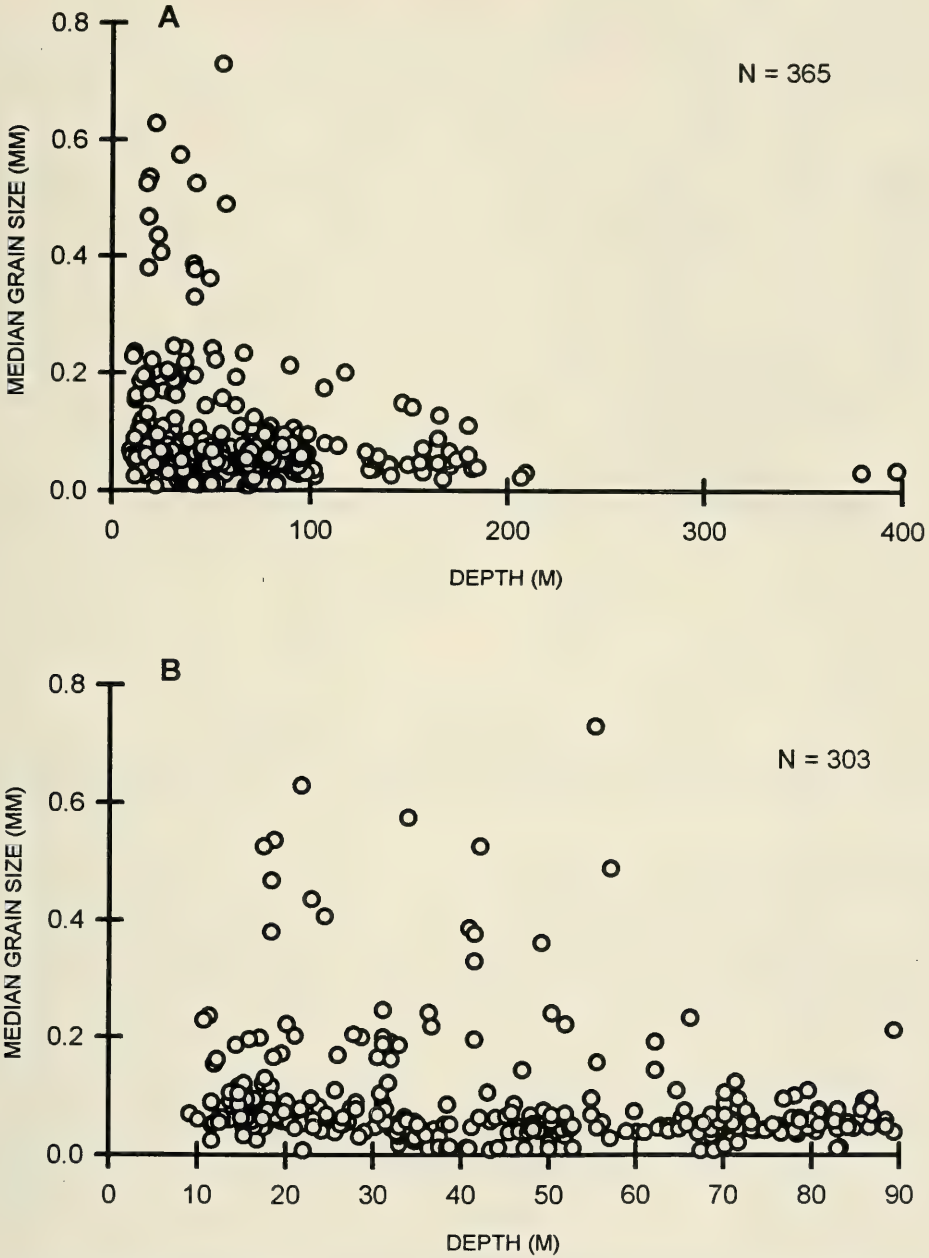


Fig. 4. Median grain size vs. depth. An expanded view of the data for samples taken in less than 90 m of water is shown in Part B.

Discussion

The relationship between depth and sediment grain size and the abundance of *Amphiodia* (*Amphispina*) spp. is not simple (Figs. 2-5). There is considerable scatter in the data. Furthermore, the relationship is not linear. Rather, the samples

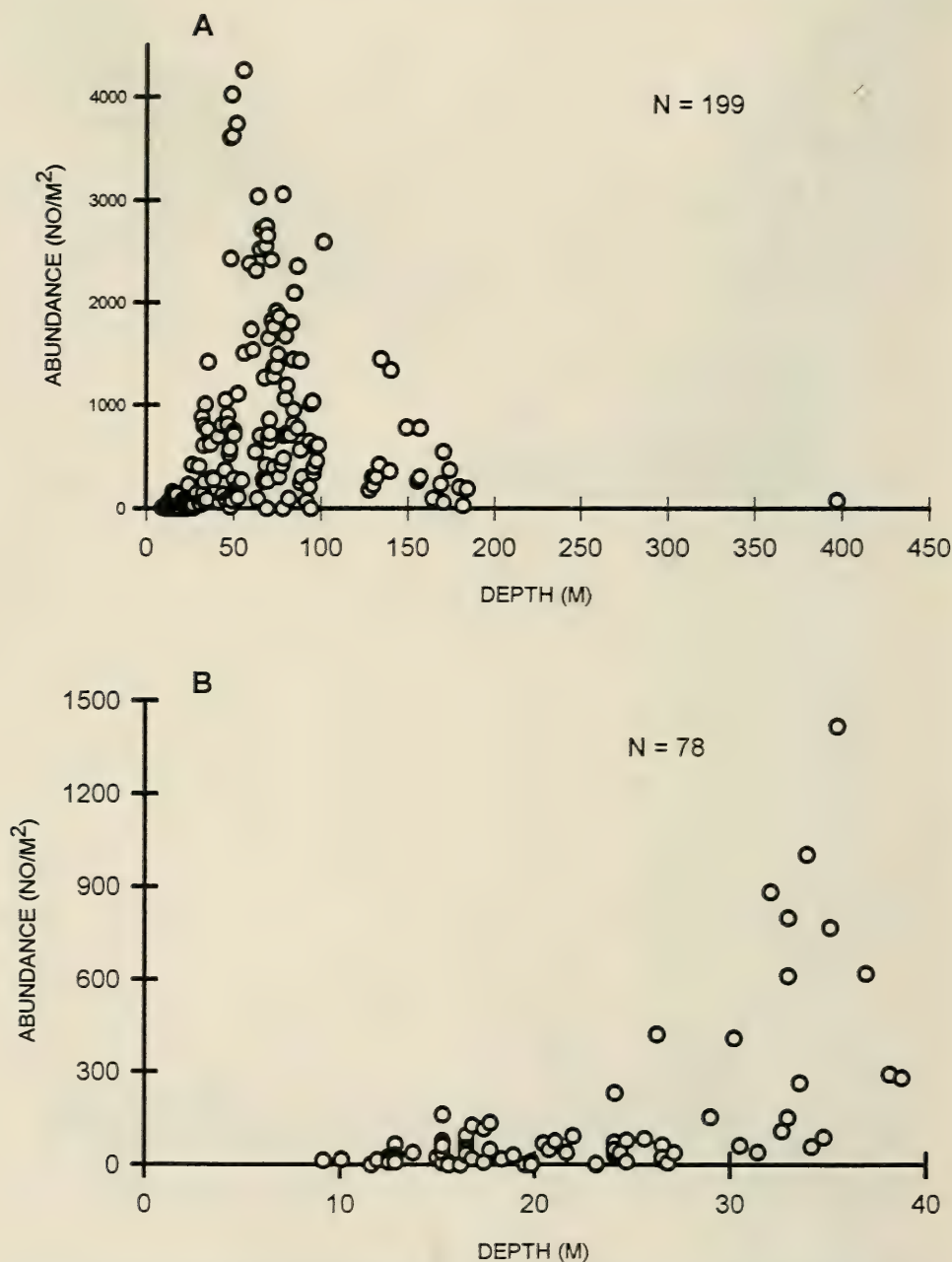


Fig. 5. Abundance of *Amphiodia (Amphispina)* spp. vs. depth in samples with median grain size between 0.035 and 0.073 mm. An expanded view of the data for samples taken in less than 40 m of water is shown in Part B.

with the highest abundances are found within a limited range and there seems to be a threshold beyond which abundances are always low.

Amphiodia (Amphispina) spp. were most abundant in water depths 48 to 102 m in sediment with median grain size between 0.035 to 0.093 mm, a diameter

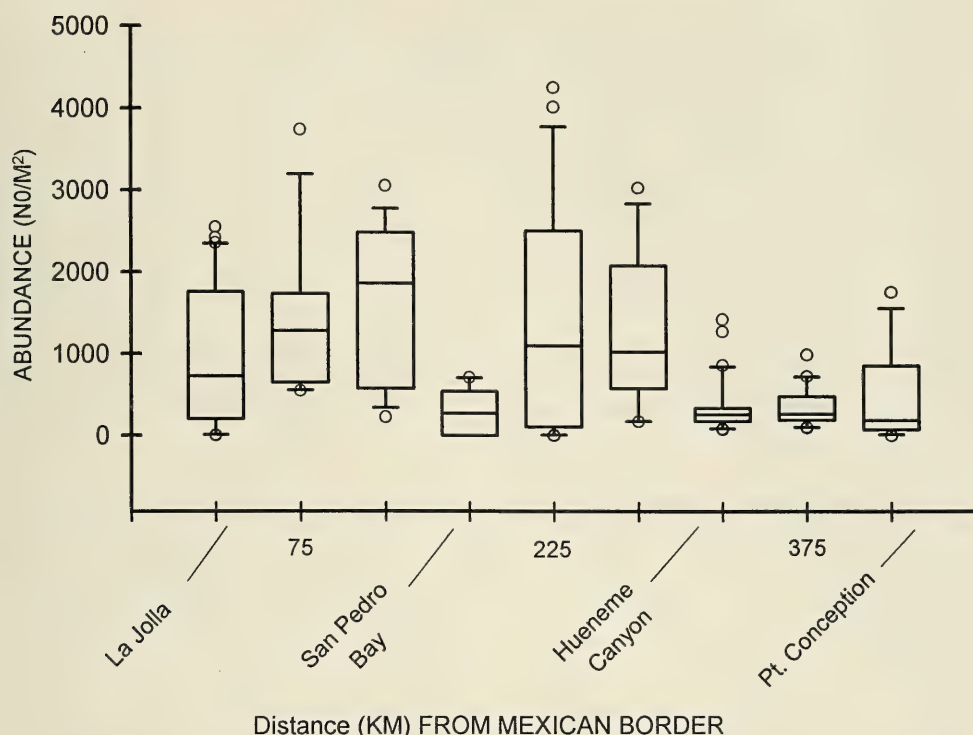


Fig. 6. Box plot of median abundance of *Amphiodia (Amphispina)* spp. in 50-km sections of the coast for samples collected between 48 and 102 meters. The edge of the box indicates the 25th and 75th percentiles; the error bars indicate the 10th and 90th percentiles.

which is classified as coarse silt to very fine sand. *Amphiodia (Amphispina)* spp. were rarely collected in less than 15 or more than 185 m of water.

Interestingly, the distribution of sediment grain size was, to some degree, independent of depth. While the number of samples with coarse sediment was higher in shallow than in deep water, samples with grain size between 0.035 and 0.073 mm were taken at all depths. However, in samples taken in less than 25 or in more than 180 m of water, the abundance of *Amphiodia (Amphispina)* spp. was low even when the sediment texture was presumably suitable. Thus, the effect of depth on the abundance of *Amphiodia (Amphispina)* spp. was, in part, independent of grain size.

Overall, *Amphiodia (Amphispina)* spp. were less abundant between Ventura and Point Conception than elsewhere in the Bight. This can, in part, be attributed to the presence of very fine and very coarse sediment in the area. To the southeast of Santa Barbara, there is a topographic high called the Carpinteria Shelf-Rise (Wimberly 1961). The sediment on the rise is sandy. To the east of the rise there is a large area of clayey silts and silts that Wimberly calls the Las Pitias Mud Deposit and the Santa Clara Prodelta deposit. To the south of Point Conception, there is an area of fine sand that is probably caused by the refraction of waves around Point Conception.

Even when the differences in sediment texture are taken into account, however, the abundance of *Amphiodia (Amphispina)* spp. north of Ventura was lower than

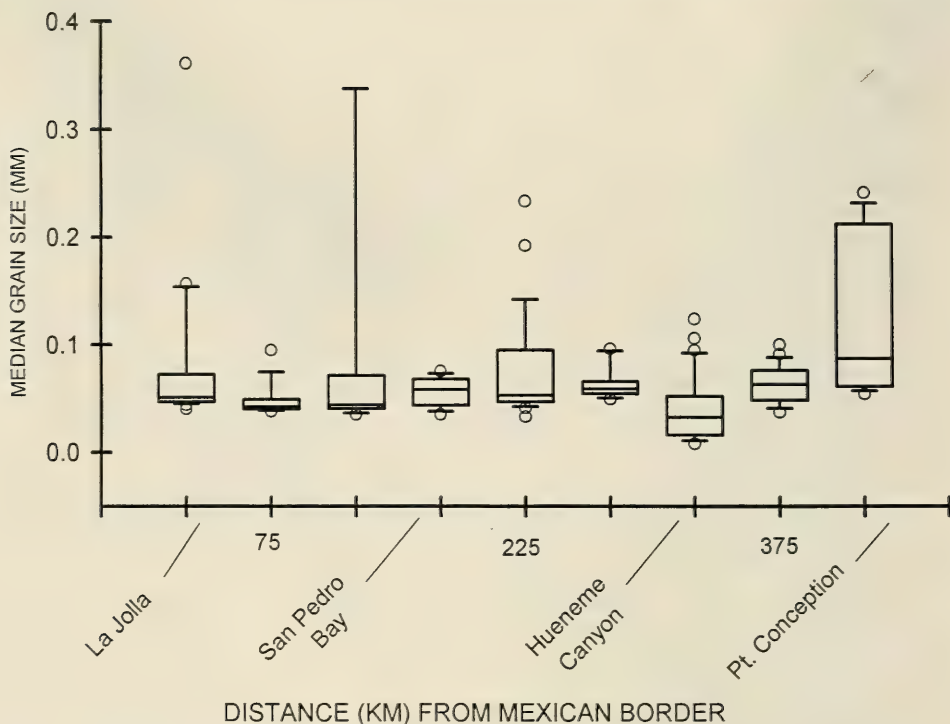


Fig. 7. Box plot of median grain size in 50-km sections of the coast for samples collected between 48 and 102 meters. The edge of the box indicates the 25th and 75th percentiles; the error bars indicate the 10th and 90th percentiles.

elsewhere in the Bight. Barnard and Ziesenhenné (1960) believed that there was a faunal break at the Hueneme Canyon. The benthic assemblage north of the canyon in 60 to 92 m was considered a separate community, called the *Amphiodia urtica*-*Cardita ventricosa* community. In this community mollusks, particularly the clam *Cyclocardia* (= *Cardita*) *ventricosa* (Gould 1850), were abundant. Barnard and Ziesenhenné proposed that the northward flowing countercurrent moved offshore at Hueneme Canyon so that the area north of the canyon was generally colder than the area south of the canyon.

The abundance of *Amphiodia* (*Amphispina*) spp. was also reduced in San Pedro Bay. In San Pedro Bay, the grain size of the sediment was within the range that is suitable for *Amphiodia* (*Amphispina*) spp. However, Barnard and Ziesenhenné (1960) suggested that, even though the median grain size was similar, the sediment in San Pedro Bay was slightly coarser than the sediment in other areas of the Bight that supported *Amphiodia urtica* communities. Barnard and Ziesenhenné included the benthic community in San Pedro Bay in the *Amphioplus hexacanthus* community. This community was similar to the *Amphiodia urtica* community, except that *Amphiodia urtica* was less abundant and the brittlestar *Amphioplus hexacanthus* H. L. Clark 1911, the brachiopod *Glottida albida* Hinds 1824 and several species of polychaetes were more abundant.

When the geographical distribution of *Amphiodia* (*Amphispina*) spp. is considered, it is apparent that some, but not all, of the pattern in abundance is attributable

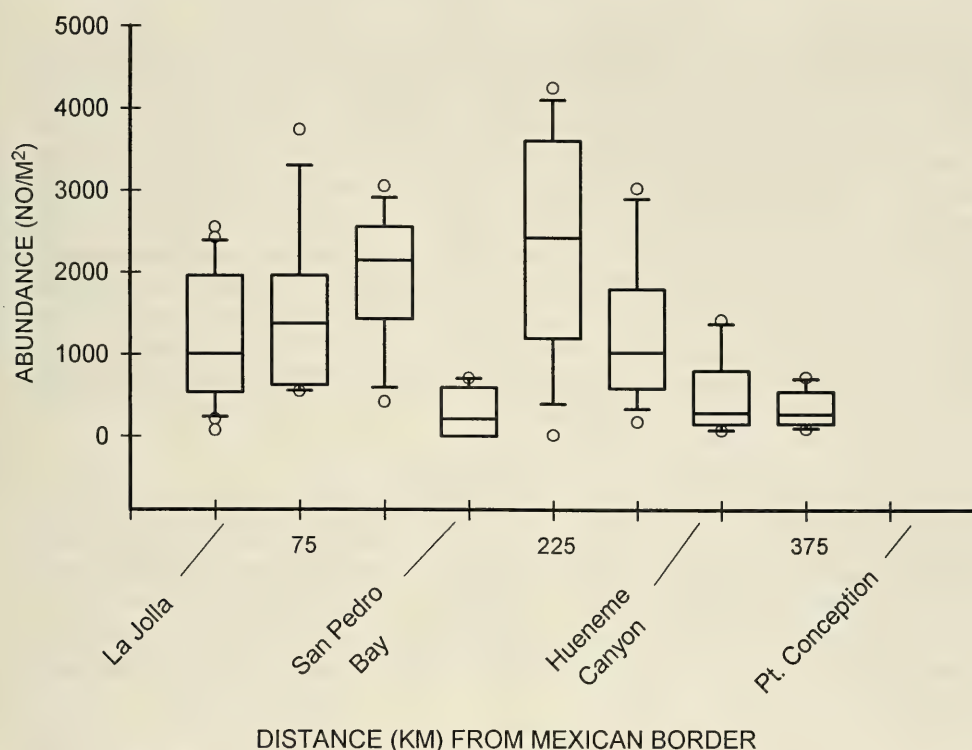


Fig. 8. Box plot of median abundance of *Amphiodia* (*Amphispina*) spp. in 50-km sections of the coast for samples collected between 48 and 102 meters with median grain size from 0.036 to 0.073 mm. The edge of the box indicates the 25th and 75th percentiles; the error bars indicate the 10th and 90th percentiles.

to the geographical distribution of sediment types. It is possible that if more or better measures of sediment texture were available, more of the distribution would be related to sediment type. However, it is also possible that other factors, including food availability, competition and predation, are affecting the distribution of the species.

Since there was a major El Niño event in 1957–1959 (e.g., Reid 1988), the question arises as to how representative the State survey data are of current conditions. The abundance of *Amphiodia urtica* measured at control stations in the municipal wastewater monitoring programs during the last ten years in Santa Monica Bay, off Orange County and off Point Loma ranges from approximately 500 to 4500 per square meter (Bergen, pers. obs.). Thus the range in abundances measured in the State survey and the monitoring programs are comparable. Unfortunately, since there has been no Bight-wide survey in recent years, it is difficult to determine if the geographical distribution of *Amphiodia* (*Amphispina*) spp. has changed. The available information suggests, however, that benthic communities may have changed since the State survey. In 1977 the Southern California Coastal Water Research Project (SCCWRP) sampled 71 stations evenly distributed between Point Conception and the Mexican Border (Word and Mearns 1979). Theirteen stations were sampled north of Ventura. The abundance of *Amphiodia* (*Am-*

phispina) spp. in these samples ranged from 300 to 1130 individuals per square meter, a range which is comparable to the range in abundance measured in the State survey. However, the clam *Cyclocardia ventricosa* was collected at only two out of thirteen stations; the abundance of *Cyclocardia* was 60 to 70 per square meter at these two stations. In the State survey *Cyclocardia* was collected at 12 out of 16 stations sampled between 50–70 m between Ventura and Point Conception. Where it was collected, the abundance of *Cyclocardia* ranged from 4 to 388 per square meter; there were more than 330 individuals per square meter at seven stations. These data suggest that the abundance of *Cyclocardia* decreased between 1959 and 1977 and that *Cyclocardia* is no longer co-dominant with *Amphiodia urtica*. However, a systematic, Bight-wide survey is required before it can be determined if the community types described by Barnard and Ziesenhenne (1969) and Jones (1969) are still applicable.

Acknowledgments

Dr. Gilbert Jones kindly provided written reports and background information on the State survey. The librarians at the Allan Hancock Foundation generously provided station logs from the R/V Velero and other material from the library. Dr. Robert Smith of EcoAnalysis, Inc., provided part of the State survey data in digital format. Dr. Gordon Hendler spent many hours checking identification of specimens from the State survey. David Tsukada drafted maps and prepared graphics.

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Mammal Surveys of the Lower Arroyo Seco Park, Pasadena, California and of Millard Canyon, Altadena, California

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Abstract. — This paper presents the results of a mammal inventory of the Lower Arroyo Seco Park, Pasadena, California and of a similar but less disturbed comparison site, Millard Canyon, Altadena, California. Results indicated that in comparison the Lower Arroyo Seco Park has within a few decades experienced a moderate loss of mammal species rabbit size and larger and a severe loss of smaller species. Local species extinctions are attributed mainly to the loss of plant associations required by habitat-specific species for foraging and shelter, and secondarily to possible interspecific competition of mouse sized mammals with pocket gophers.

The City of Pasadena has begun implementation of a *Master Plan For The Lower Arroyo Seco Park* (Studio 606 1988). The purpose of this plan is to restore a more natural habitat to the park to enhance its value as an urban sanctuary for humans and animals (Cairns 1987). As far as could be determined the mammals of this site had not been inventoried prior to this survey. The following inventory of the mammals of the Lower Arroyo Seco Park, Pasadena, California, and of a similar but less disturbed site, Millard Canyon, Altadena, California, is intended to serve as a baseline of current species diversity for comparison with later inventories, and as a source of information for those interested in the effects of habitat loss and human activity on species diversity.

Site Description

Lower Arroyo Seco Park

The Lower Arroyo Seco Park, Pasadena, California, (Arroyo) is a 2.8 km section of the Arroyo Seco stream channel that stretches from the San Gabriel Mountains through several urban communities, and ends at the Los Angeles River. Until the last few decades this was a continuous habitat corridor which facilitated animal dispersal (Adams and Dove 1989), but it has now been broken into separate segments by land development. The section containing the Arroyo survey site has been isolated from other areas of natural habitat since about 1927 (Pasadena Historical Society 1992). The Arroyo varies in width from about 53 meters to about 0.4 kilometer and is bracketed on the East and West by cut banks up to approximately 30 meters high. The climate of this geographic area is Mediterranean, characterized by cool, moist winters and hot, dry summers. Winter temperatures can reach highs of 25°C with lows just above freezing, while Summer

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temperatures can exceed 39°C. Elevation of the site ranges from approximately 203 meters to about 290 meters above sea level (Studio 606 1988). The Arroyo is bisected by a concrete flood control channel that was constructed in the late 1930's and early 1940's. A dirt access road runs along both sides of the flood channel and several foot and bridle paths wind throughout the Arroyo.

The historic plant associations of the Arroyo are: Meadow, Riparian, Oak Woodland, Coastal Sage Scrub, and Chaparral. The major plants of these associations are: Riparian—*Salix* species (Willows), *Alnus rhombifolia* (White Alder) and *Plantanus racemosa* (Sycamore); Meadow—native perennial grasses, *Nemophila menziesii* (Baby Blue-eyes), *Escholtzia californica* (California poppy), and *Lupinus* sp. (Lupine); Oak Woodland—*Quercus agrifolia* (Coast Live Oak), *Quercus engelmanni* (Engelman Oak), and *Juglans californica* (California Walnut); Coastal Sage Scrub—*Salvia apiana* (White Sage), *Sambucus mexicana* (Elderberry), *Artemisia californica* (California sage), *Rhus integrifolia* (Lemonadeberry); Chaparral—*Ceanothus species* (Wild Lilac), *Arctostaphylos ilicifolia* (Manzanita), *Heteromeles arbutifolia* (Toyon), *Prunus ilicifolia* (Hollyleaf Cherry), *Salvia mellifera* (Black Sage), and *Eriogonum fasciculatum* (California Buckwheat). This plant classification was based on *A California Flora* by Munz (1974).

Except for the Meadow group the Arroyo has remnants of all the indicator species above. Still present are 2 of 3 Riparian species (*Plantanus racemosa*, *Salix lasiolepis*), 2 of 3 Oak Woodland species (*Quercus agrifolia*, *Juglans californica*), 1 of 4 Coastal Sage Scrub species (*Sambucus mexicana*), and 4 of 6 Chaparral Species (*Heteromeles arbutifolia*, *Prunus ilicifolia*, *Salvia mellifera*, *Eriogonum fasciculatum*). No attempt was made to actually measure the area occupied by these species but in general the shrubs occur as patches of about a 100 square meters or less and the trees are solitary or in groves of a few trees.

Today exotic annual grasses (examples are *Festuca megalura* [fescue] and *Bromus diandrus* [ripgut chess]) carpet the floor and gentle slopes in the Arroyo. These areas are mowed at the end of the Spring growing season when the grasses begin to dry out. The largest remaining patch of Coastal Sage Scrub, which has some Chaparral species intermingled, is no larger than about a hectare and lies at the north end of the study site near the Colorado Street bridge. Just north of this bridge and adjacent to the study site (not included in this inventory) is the only surviving Riparian habitat. It has been heavily disturbed by recreational activities and has both a reduced groundcover layer and understory layer. Oaks and sycamores occur throughout the Arroyo as lone trees, mainly on or near the Arroyo sides, and oaks form a small, discontinuous grove at the north end of the site just south and east of the Sage/Chaparral patch. There are a few mature Eucalyptus trees (species not identified) on the study site, remnants of the trees planted when the Arroyo was being used for woodlots (Studio 606 1988).

There are several artificial structures on the Arroyo floor. The Arroyo is bisected by a concrete flood control channel, constructed in the late 1930's and early 1940's. This entrainment of the Arroyo Seco stream eliminated the major water source for wildlife in the Arroyo. On the eastern side of the site, just south of the entrance road, is a small clubhouse and a concrete fly rod casting pond surrounded by a wide, paved walkway with park benches. The asphalt and gravel parking area lying adjacent to the west side of the pond covers approximately a half hectare. West of the flood channel there is an archery club house. The archery range runs

about 1 kilometer along the base of the western cut bank and consists of wooden shelters and straw bales and pipe and wire target supports. A dirt access road runs along both sides of the flood channel and several foot and bridle paths wind throughout the Arroyo.

Millard Canyon

The comparison site, Millard Canyon, Altadena, California, is about 11.3 kilometers generally north/northeast upstream from the Arroyo, at an approximate elevation of 531 meters to 713 meters above sea level (Arroyo Seco Council 1991). Millard Creek provides year-round water, although during drought years it is reduced to a slow trickle between pools. Due to adiabatic cooling Millard averages approximately 8°C cooler than the Arroyo and the closed canopy in the canyon bottom and the high, steep hills enclosing the site provide both shade and some protection against rapid evaporation. In years of average precipitation for this semi-arid area the creek flows freely over a boulder-strewn channel.

The streamside Riparian association at this site includes *Salix lasiolepus*, *Umbellularia* sp. (California Bay), *Alnus rhombifolia*, and *Plantanus racemosa*. A few meters above the stream bank the Riparian gives way to Oak Woodland, dominated by *Quercus agrifolia*, which in turn grades into intact Coastal Sage Scrub habitat on the semi-arid slopes surrounding the canyon.

The Coastal Sage Scrub surveyed is an estimated hectare portion of the scrub which blankets the surrounding hills. This site faces south and is about 30 meters up a steep slope from the stream channel near the edge of a dirt fire road.

There is a six site walk-in campground at the north end of the estimated 2.6 kilometers of the canyon bottom sampled for this survey. Scattered throughout the canyon are private residences (walk-in only for the most part) which date from as early as the 1940's. Some exotic species of ornamentals and groundcovers have invaded the areas immediately adjacent to these residences. There is a hiking/biking trail running beside the creek that receives light to moderate traffic, depending on the season and the day of the week. The dirt fire roads in the surrounding hills are heavily utilized by mountain bikers.

Methods

In order to have an indicator of the mammal species with a high probability of having utilized the plant associations in the Arroyo prior to anthropocentric damage lists of these species were compiled from field guides and taxonomic texts (Hall and Kelson 1959; Ingels 1965; Whitaker 1980). Shrews and moles, which are rarely caught in live box traps, were excluded from this list, as were bats and bears. This resulted in a list of 28 mammal species (Tables 1, 2).

Arroyo Seco Survey

Between May 6, 1992 and September 3, 1992 a total of 1200 trap nights (one trap for one night) were completed, 300 in each of four arbitrarily designated habitat divisions: grassland without a litter layer, grassland with a litter layer, slopes with more than 50% cover, slopes with 50% or less cover. The traps were set about three meters apart in rows. Distance between rows varied due to terrain and vegetation but averaged about four meters. In this way essentially all accessible areas were trapped at least once. In order to reduce the possibility of a chance

Table 1. Possible mammals/results of trapping survey for rats and mice.

California pocket mouse	<i>Perognathus californicus</i>	P (M)
Little pocket mouse	<i>Perognathus longimembris</i>	ABSENT
Agile kangaroo rat	<i>Dipodomys agilis</i>	P (A*)
Western harvest mouse	<i>Reithrodontomys megalotis</i>	P (A*) (M)
Brush mouse	<i>Peromyscus boylii</i>	P (A*) (M)
California parasitic mouse	<i>Peromyscus californicus</i>	P (A*) (M)
Deer mouse	<i>Peromyscus maniculatus</i>	ABSENT
So. grasshopper mouse	<i>Onychomys torridus</i>	ABSENT
Dusky-footed wood rat	<i>Neotoma fuscipes</i>	P (A) (M)
California meadow vole	<i>Microtus californicus</i>	P (M)
Black rat	<i>Rattus rattus</i>	P (A) (M)

Key: P = present this survey; (A) = Arroyo; (M) = Millard Canyon; * = Historic (Museum only).

omission the grassland portion was subjected to an additional 50 trap nights, concentrated on the transition zones between habitat types and in areas adjacent to water sources, locations assumed to offer a high probability of capture due to their relatively greater plant diversities.

Only one type of trap was used in the Arroyo, the $8\frac{1}{2} \times 3 \times 3\frac{1}{2}$ inch aluminum box Sherman Live Trap. The first 100 and last 700 traps were baited with plain rolled oats. In an effort to eliminate bait type as a factor in the lack of capture success, the remaining 400 traps were baited with oats combined with one or more of the following: dry dog kibble, wild bird seed mix, apple and carrot pieces.

The large mammal portion of the study consisted of the use of tracking sets (Conner et al. 1983; Lowery 1990; Murie 1954) and verbal interviews of local residents and park users. The tracking sets were placed on game trails and in spaces in shrub rows just at dusk and checked shortly after sunrise to minimize human disturbance. Two sets were constructed on each of 10 nights for a total of 20 sets.

Mrs. Lynn Barkley, Collections Manager, Section of Mammalogy, Los Angeles County Museum of Natural History (LACMNH), supplied a list of the mammal specimens in the museum's collection from the Arroyo Seco area.

Table 2. Possible mammals/results of track and visual surveys.

Opossum	<i>Didelphis virginiana</i>	P (A) (M)
Coyote	<i>Canis latrans</i>	P (A) (M)
Cougar	<i>Felis concolor</i>	P (M)
Bobcat	<i>Felis rufus</i>	p (A*) (M)
Raccoon	<i>Procyon lotor</i>	P (A) (M)
Ringtail	<i>Bassariscus astutus</i>	P (M)
Striped skunk	<i>Mephitis mephitis</i>	P (A) (M)
Spotted skunk	<i>Spilogale putorius</i>	P (M)
Long tailed weasel	<i>Mustela frenata</i>	ABSENT
Mule deer	<i>Odocoileus hemionus</i>	P (A) (M)
Merriam's chipmunk	<i>Eutamias merriami</i>	ABSENT
Calif. chipmunk	<i>Eutamias obscurus</i>	P (M)
Brush rabbit	<i>Sylvilagus bachmanii</i>	P (A) (M)
Cottontail rabbit	<i>Sylvilagus audubonii</i>	P (M)
Gray squirrel	<i>Sciurus griseus</i>	P (A) (M)
Calif. ground squirrel	<i>Spermophilus beecheyii</i>	P (A) (M)
Calif. pocket gopher	<i>Thomomys bottae</i>	P (A) (M)

Key: P = present this survey; (A) = Arroyo; (M) = Millard Canyon; * = Historic (Museum only).

Millard Canyon Survey

The comparison site, Millard Canyon, does not have the open grasslands of the Arroyo and due to the narrowness and steepness of the canyon walls also does not have as much casually accessible surface area. Therefore a proportional equivalent of 800 Sherman trap nights was utilized between October 7, 1992 and November 26, 1992. In addition to the Sherman traps, four squirrel-size and one opossum-size wire Tomahawk live traps were each set for five trap nights. Various combinations of carnivore and omnivore baits were utilized.

Millard's ground surface is not amenable to tracking sets. Instead, a survey (with attached letter of explanation and a stamped, self-addressed return envelope) containing a common name check list of the mammals larger than trap size expected in the canyon, with a choice of frequencies of sighting (once; occasionally [two to six times a year]; frequently [more than six times a year]), was distributed to 15 of the residences within and adjacent to Millard Canyon. Six completed surveys were returned.

Results

Lower Arroyo Seco

At the Arroyo site 1250 trap nights resulted in the capture of three *Neotoma fuscipes* (Dusky-footed Wood Rats) and three *Rattus rattus* (Black Rats), a 0.5% return for effort. *Neotoma fuscipes* was taken near either oak/laurel or sage/buckwheat plant associations. *Rattus rattus* were caught near Algerian Ivy that had invaded the oak/laurel woodland from residences at the edge of the Arroyo.

Numerous *Spermophilus beecheyi* (California Ground Squirrels) were sighted on each visit to the Arroyo in varied plant associations. *Thomomys bottae* (California Pocket Gophers) were sighted twice. Their burrow entrances pock the grasslands, making hazardous walking conditions. *Sciurus griseus* (California Grey Squirrels) were common at the Arroyo's east rim in various species of trees. At the north end of the site *Sylvilagus bachmani* (Brush Rabbits) were frequently sighted bounding into brushy cover in an area of sage scrub.

Track sets provided sign in the following frequencies: *Odocoileus hemionus* (Mule Deer)—3; Fox (species undetermined: most likely introduced *Vulpes vulpes* [Red Fox] less likely native *Urocyon cinereoargenteus* [Grey Fox])—2; *Neotoma fuscipes*—1; *Procyon lotor* (Raccoon)—1; *Didelphis virginiana* (Opossum)—2. Scats from fox (4) confirmed the track indications. One *Mephitis mephitis* (Striped Skunk) was found dead. The tracks of a *Procyon lotor* were observed in the mud at the edge of the creek just north of the check dam under the Colorado Street Bridge.

Numerous interviews of local residents and park users invariably resulted in the following mammals being reported: *Odocoileus hemionus*, *Canis latrans* (Coyote), and *Didelphis virginiana* in addition to the above rodent and lagomorph species.

The search of the LACMNH files for historic specimens from Arroyo Seco yielded the following species, all collected in 1904: *Peromyscus boylii* (Brush Mouse), *Peromyscus californicus* (California Mouse), *Reithrodontomys megalotis* (Harvest Mouse), *Dipodomys agilis* (Agile Kangaroo Rat), *Lynx rufus* (Bobcat), and *Urocyon cinereoargenteus*.

Millard Canyon

In 800 trap nights at the Millard site a total of 86 individuals were captured, a return for effort rate of 10.8%. The following species of small mammals were recorded: 52 *Peromyscus boylii* (37 adults, 15 juveniles); 23 *Peromyscus californicus* (12 adults, 11 juveniles); 5 *Neotoma fuscipes*; 1 *Reithrodontomys megalotis*; 2 *Microtus californicus* (California Meadow Vole); 3 *Peromyscus eremicus* (Cactus Mouse); 3 *Perognathus californicus* (California Pocket Mouse); 1 *Eutamias obscurus* (California Chipmunk). The species *E. obscurus* rather than *E. merriami* was chosen for the chipmunk because the tail was 105 mm and the ear 19 mm. Merriam's chipmunk's tail is given (Jameson and Peeters 1988) as 110 mm to 124 mm and the ear as 16 mm to 18 mm, while same measurements on the California subspecies are listed as 75 mm to 120 mm and 13 mm to 40 mm, respectively. The specimen also had dark reddish dorsal stripes and rust on the sides.

Peromyscus boylii and *Peromyscus californicus* were both taken in three habitat types: Oak/laurel Woodland, Riparian and Coastal Sage Scrub. *Neotoma fuscipes* occurred in Oak/Laurel, Sage Scrub, and on rocky slopes near bushes with branches to ground level. *Perognathus californicus*, *Eutamias obscurus*, and *Peromyscus eremicus* were trapped in the Sage Scrub. *Reithrodontomys megalotis* was caught in the transition zone between Sage Scrub and a grassy meadow-like open area. *Microtus californicus* was taken only in a shallow, grass and green forb covered depression of about 15 meters diameter at the junction of the Sage Scrub and Oak Woodland.

Odocoileus hemionus, *Sciurus griseus*, *Thomomys bottae*, and *Spermophilus beecheyi*, in addition to untended domestic dogs and cats, were directly observed on more than one occasion. *Canis latrans* was sighted once.

The six survey forms returned by local residents resulted in the following additional species being confirmed present by more than one respondent: *Felis concolor* (Cougar); *Sylvilagus bachmanii*; *Sylvilagus audubonii* (Desert Cottontail); *Spilogale putoris* (Spotted Skunk); *Felis rufus* (Bobcat); *Didelphis virginiana*; *Basariscus astutus* (Ring-tail); *Urocyon cinereoargenteus*.

On the survey form the cotton tail and brush rabbits were described briefly (Cottontail [brown with rust nape and legs, slender] and Brush [brown mottled with black, rounded shape]). A question was raised concerning the accuracy of these reports of Desert Cottontail and a review of the returned forms showed the following: no rabbits reported—3/6; cottontail only reported—2/6; both species reported—1/6. The respondent who reported sighting both species "frequently" was the year-round resident camp caretaker at Millard Canyon for several years and undoubtedly had the most opportunities for observing the wildlife. However, until officially confirmed these reports of Desert Cottontail at this site will remain questionable.

Conclusion

The Lower Arroyo Seco Park, Pasadena, California, a highly disturbed semi-natural area surrounded by urban development, was surveyed for mammals to provide a foundation for future studies after scheduled habitat improvements are in place. The results were compared to a list of mammals known to utilize plant

associations present in the Arroyo prior to anthropocentric disturbance. A survey of Millard Canyon, Altadena, California, which is part of the same watershed, contains the same habitat types that the Arroyo had historically, and, while supporting residences, campground and hiking trails, has sustained only moderate habitat loss, served as a crude indicator of the species that could be expected in the contemporary Arroyo if the plant associations were more intact.

Using the list of "possible" mammals (Tables 1, 2), which excluded bats, shrews, moles, and bears and was considered a probable underestimate of original diversity outside of these species, the survey results indicated that the Arroyo now has only 28.6% of the expected mammals up to squirrel size and 46.2% of the larger mammals. The Millard inventory results showed significantly greater diversity, with 71.4% of mammals less than squirrel size and 92.3% of larger mammals present. By eliminating Bobcat, Ringtail and Cougar, recorded for Millard which is contiguous with a large protected mountain nature reserve (Angeles National Forest) but, unlike the foxes and coyotes that still frequent the Arroyo, are more sensitive to human presence and could not be expected in a habitat island within urban development (Gittleman 1989; Wirtz and Quinn 1992), the loss of species in the Arroyo was found to be about 72.8% when compared to the Millard results.

Several possible explanations for this reduction in mammal diversity were considered (Koler 1993), including insufficient food resources, interspecific competition, predation pressure both past and present, and the loss of specific plant associations (Connel 1983; Crowell 1973; Dueser and Brown 1980; Eisenberg 1962; Grant 1971; Nee and May 1992). The three most likely hypotheses are: loss of specific plant associations; past predation reduced small mammal populations below viable numbers, and isolation from sources of immigration prevented reestablishment; interspecific competitive exclusion of mice by pocket gophers. As the Arroyo floor has been mostly cleared of brush, the loss of the shrub layer is felt to be the most likely major cause of species loss since the majority of the locally extinct species are dependant upon a shrub layer for foraging and shelter (Dueser and Brown 1980; Jameson and Peeters 1988; Meserve 1976; Scott and Dueser 1992; Vaughn 1954), especially on the Coastal Sage Scrub plant community, which now is present only in a few isolated patches less than a hectare in total area. Although no literature could be located describing exclusion of mice by pocket gophers, references were found to field and laboratory studies of exclusion of mice by voles (Grant 1971; Lidicker 1966; Morris 1969). Voles have autecological parameters sufficiently similar to that of the gophers to warrant an extrapolation. Given the extremely high gopher population of the Arroyo site this exclusion hypothesis has the second greatest potential as an explanation of the absence of mice in the Arroyo. In addition, it is highly likely that predation on the small mammal populations following isolation of the Arroyo from larger natural areas with potential immigrants was an important factor in their initial decline, although at present the predator abundance appears to be minimal.

There are several possible future studies that could expand upon this survey's results and clarify its conclusions. One obvious project would be trapping around the residences on the Arroyo's rim to identify the species present there, such as *Mus musculus*, that could be expected to utilize the Arroyo but that were absent from these results. Another extremely valuable addition would be competitive exclusion experiments with *Thomomys* and *Peromyscus* or *Mus* to test the hy-

pothesis that such exclusion is a significant factor in the absence of mice from the Arroyo. After the *Master Plan* completion, reintroduction experiments with and without predators and *Thomomys* fenced exclusion plots could provide information useful to restoration ecologists. If tall pole raptor perches were installed to make the Arroyo more inviting to these potential *Thomomys* predators their impact on all the rodent populations could be determined. It is hoped that urban wildlife and restoration ecologists will take advantage of the unique opportunities for research presented by the Lower Arroyo Seco Park's habitat restoration (Cairns 1987).

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Research Notes

A New Record of the Miocene Rabbit *Hypolagus fontinalis* from West Central Nevada

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During a survey of the mammalian fossils from west central Nevada in the collections of the Natural History Museum of Los Angeles County (LACM), a previously unrecognized specimen (LACM 138022) of the Miocene rabbit *Hypolagus fontinalis* was discovered. The specimen was recovered from the lower member of the Truckee Formation at Brady Pocket (locality LACM 6229), which occurs about 10 miles northwest of Brady Hot Springs, Churchill County, Nevada (complete locality data on file at the LACM).

Local exposures of the Truckee Formation occur over a large area of west central Nevada, including the Hot Springs Mountains of Churchill County, the Trinity Range of Pershing County, the Truckee Range of Washoe County, and the eastern Virginia Range of Lyon County (Bonham 1969; Moore 1969; Willden and Speed 1974). The formation was first recognized by King (1878), wherein the type section was designated as the northeastern corner of the Hot Springs (Kawsoh) Mountains. Subsequent investigators have also applied the name Truckee Formation to a series of sedimentary rocks exposed in the central Virginia Range of Storey and Lyon Counties, and in the Reno and Verdi areas of Storey County. However, these rocks are now regarded as correlatives of the Coal Valley Formation (Axelrod 1956; Bonham 1969; Kelly in prep.). In the type area, the Truckee Formation is comprised of fluvio-lacustrine sediments characterized by altered basalt tuff, diatomite, limestone, sandstone, bentonitic clay, and basalt pebble to cobble conglomerate (Axelrod 1956; Bonham 1969). Axelrod (1956) recognized three members within the Truckee Formation; lower, middle, and upper. The lower member is characterized by basalt tuffs, sedimentary breccia, sandstones, and minor bentonitic clays. The middle member is characterized by a thick lacustrine deposit of diatomite. The upper member is characterized by limestones, sandstones, bentonitic clays, and basalt pebble conglomerates.

Mammalian fossils are a relatively rare phenomenon in the Truckee Formation with most specimens represented only by fragmentary remains. Four fossil mammal bearing sites have been recorded in the Truckee Formation: 1) the Kawsoh Mountain Site; 2) the Hazen Site (University of California Museum of Paleontology [UCMP] V-3943); 3) the Nightingale Site (UCMP V-4844); and 4) the Brady Pocket Site (UCMP V-4845, LACM 6229).

The Kawsoh Mountain Site has yielded a single specimen, a partial cheek tooth of an indeterminate rhinocerotid, from an unknown stratigraphic position that could be either Clarendonian or Hemphillian (North American Land Mammal

Ages) in age (King 1878; Macdonald 1956; Stirton 1939; Yen 1950). The Hazen Site, which occurs in the upper part of the lower member, has yielded an indeterminate carnivore and indeterminate equid that could be either Clarendonian or Hemphillian in age (Stirton 1939; Axelrod 1948; Macdonald 1949, 1956; Macdonald and Pelletier 1958). The Brady Pocket and Nightingale Sites occur about one mile apart along Nightingale Road, Churchill County, in the lower part of the lower member with the Brady Pocket Site only slightly lower stratigraphically than the Nightingale Site (Macdonald 1956). Macdonald (1956 p. 187) and Macdonald and Pelletier (1958 p. 370) referred the taxa from the Nightingale and Brady Pocket Sites to the Nightingale Road Fauna. Macdonald (1956 p. 188) referred the Nightingale Road Fauna along with the taxa from the Hazen and Kawsoh Sites to the Truckee Fauna. Tedford et al. (1987 p. 162) referred the taxa from the Brady Pocket and Nightingale Sites to the Brady Pocket and Nightingale Road Local Faunas. The Brady Pocket Site has previously yielded the following taxa: Leporidae, gen. indet.; *Tardontia occidentale*; *Mylagaulus* sp. indet.; *?Hystriopsis* sp. indet.; *Eucastor* near *E. lecontei*; *Lutra* sp. indet.; *?Epicyon diabloensis*; Mustelidae, gen. indet.; Felidae, gen. indet.; Mammutidae or Gomphotheriidae, gen. indet.; Tapiridae, gen. indet.; *Cormohipparion occidentale*; *Ustatochoerus* sp. indet.; *Aepycamelus bradyi*; and Camelidae, gen. indet. The Nightingale site has yielded the following taxa: *Lutra* sp. indet.; Mustelidae, gen. indet.; and Mammutidae or Gomphotheriidae, gen. indet. The *Lutra*, mustelid, and proboscidean specimens from the Nightingale Site cannot be differentiated taxonomically from those of the Brady Pocket Site (Macdonald 1956; Kelly in prep.). Macdonald (1956) and Macdonald and Pelletier (1958) were correct in referring the taxa from the Brady Pocket and Nightingale Sites to a single fauna because they represent an assemblage of fossil mammals of specific taxonomic composition. However, the assemblage should be regarded as a local fauna, the Nightingale Road Local Fauna, because it was recovered from two sites that are closely spaced stratigraphically and geographically. The shared occurrence of *Eucastor*, *?Epicyon diabloensis*, *Cormohipparion occidentale*, and *Ustatochoerus* indicates a late Clarendonian (late Miocene) age assignment for the Nightingale Road Local Fauna (Macdonald 1956; Macdonald and Pelletier 1958; MacFadden 1984).

The rabbit specimen (LACM 138022) from Brady Pocket, a partial left dentary with P_3 - M_2 , is well preserved with the teeth at moderate wear stage (Fig. 1). Species of fossil rabbits (Mammalia, Lagomorpha, Leporidae, Archaeolaginae) are differentiated primarily on the morphology of the upper second premolars and lower third premolars (White 1987). The specimen from Brady Pocket can be confidently assigned to the archaeolaginine *Hypolagus fontinalis* Dawson, 1958, because the P_3 exhibits the following suite of diagnostic characters: 1) moderate in size, as compared with other species of *Hypolagus*, with the greatest antero-posterior dimension ($A-P$) = 2.77 mm and greatest transverse dimension (TR) = 2.38 mm; 2) no reentrant folds are present along the lingual enamel wall; 3) the posteroexternal reentrant, a fold or indentation along the posterior half of the labial enamel wall, is deflected slightly posteriorly and extends about 47% across the width of the occlusal surface; and 5) the anteroexternal reentrant, a fold or indentation along the anterior half of the labial enamel wall, extends about 17% across the width of the occlusal surface. Additional measurements of LACM 138022 are as follows (individual tooth measurements were taken to the nearest

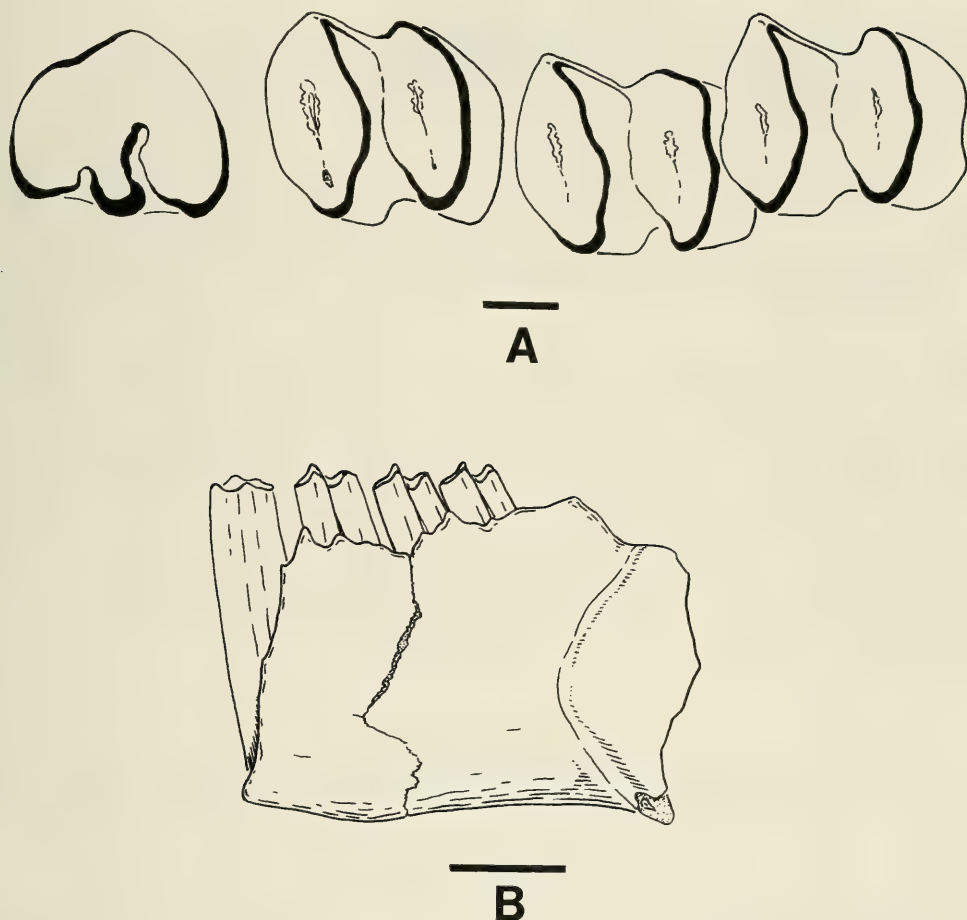


Fig. 1. *Hypolagus fontinalis*, partial left dentary with P_3 - M_2 , LACM 138022. A, occlusal view of P_3 - M_2 . B, lateral view of dentary. Scales, A = 1 mm, B = 5 mm.

.01 mm using a dissecting microscope with an optical micrometer disc; all others were taken with dial calipers to the nearest 0.1 mm): P_4 , A-P = 2.64 mm, TR = 2.78 mm; M_1 , A-P = 2.50 mm, TR = 2.72 mm; M_2 , A-P = 2.58 mm, TR = 2.72 mm; P_3 - M_2 length = 10.4 mm; and the depth of the dentary below M_1 = 10.5 mm.

Macdonald (1956) referred five calcanea and some fragmentary cheek teeth from the Brady Pocket Site to the Leporidae, gen. indet. Whether these specimens represent *H. fontinalis* cannot be determined because the calcanea of similar sized rabbit species are indistinguishable and the small sample of fragmentary cheek teeth lack the diagnostic P^2 or P_3 .

The geologic range of *H. fontinalis* is middle to late Miocene, wherein it is known from the late Barstovian to the late Clarendonian (North America Land Mammal Ages), or from about nine to 14.5 million years before present. *Hypolagus fontinalis* has been previously recorded in the following faunas (Dawson 1958; White 1987): 1) the late Barstovian Barstow Fauna from the Barstow Formation of southern California; 2) the late Clarendonian Big Spring Canyon Local Fauna

from the Ogallala Group of South Dakota; 3) the late Clarendonian Fish Lake Valley Local Fauna from the Esmeralda Formation of southern Nevada; and 4) the Clarendonian Quinn Canyon Local Fauna from the Ash Hollow Formation of Nebraska. The specimen of *H. fontinalis* from Brady Pocket represents the first rabbit species identified from the Truckee Formation. The occurrence of *H. fontinalis* at Brady Pocket extends the paleogeographic range of this species in Nevada about 250 km northward. Although known from the Barstovian, *H. fontinalis* is most common in late Clarendonian faunas and this fact further supports a late Clarendonian (late Miocene) age assignment for the lower member of the Truckee Formation.

During the deposition of the lower member of the Truckee Formation, the faunal evidence indicates that the paleoenvironment was probably characterized by grasslands or open woodlands with thicker woodlands occurring along streams and small lakes. The lakes and streams were probably perennial, as indicated by the presence of fish, the beaver *Eucastor*, the mountain beaver *Tardontia*, and the otter *Lutra*. The lakes and streams probably supported riparian woodlands suitable for browsing animals such as mastodons and tapirs, whereas, further from the watercourses, grasslands or open woodlands supported grazing animals, such as the horse *Cormohipparion* and the rabbit *Hypolagus*. Tuffaceous sediments in the formation indicate that the depositional basin was periodically supplied with volcanoclastic debris from nearby highlands.

Acknowledgments

I am indebted to John A. White of the University of Arizona for his help in confirming the identification of the rabbit specimen described herein.

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Reproduction in the California Mountain Kingsnake, *Lampropeltis zonata* (Colubridae), in Southern California

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The California Mountain Kingsnake, *Lampropeltis zonata* (Blainville 1835), ranges from southern Washington to northern Baja California, frequenting the mountains of coastal and interior California and occurring from sea level to around 2750 m (Stebbins 1985). There are only fragments of information on the reproductive biology of this species. Wright and Wright (1957) reported it to be oviparous; Cunningham (1959) reported a female from San Bernadino County that laid 3 eggs July 18; Perkins (1952) reported that a clutch of *L. zonata* eggs hatched in 63 days. According to De Lisle et al. (1986), mating occurs in April, 3–8 eggs are laid in June, and hatching takes place in August. Stebbins (1985) reported clutches of 3–8 eggs are laid June–July. Rossi and Rossi (1995) gave a range of 3–9 eggs. McGurty (1988) reported May matings and June or July ovipositions. Other information on the biology of *L. zonata* is summarized in Zweifel (1974). McGurty (1988) published on the natural history of *L. zonata*. Schoenherr (1976) gave locality records for *L. zonata* in the San Gabriel Mountains, Los Angeles County. The purpose of this report is to provide information on reproduction of *L. zonata* in southern California.

I present reproductive data from 35 *L. zonata* (21 males, 12 females from southern California; 2 males from Santa Cruz County) and body sizes in mm (snout–vent length, SVL) from 5 neonates in the herpetology collections of the Natural History Museum of Los Angeles County (LACM)—Los Angeles and the San Diego Natural History Museum (SDSNH)—San Diego. I excluded specimens that had been maintained in captivity after capture. Voucher numbers of specimens examined by county are given in Appendix 1. Counts were made of oviductal eggs and enlarged follicles. The left gonad was removed for histological examination, embedded in paraffin, and sectioned at 5 μ m. Slides were stained with Harris' hematoxylin followed by eosin counterstain. Testes slides were examined to determine the spermatogenic stage of the male cycle; ovarian slides were examined for the presence of yolk deposition (vitellogenic granules). Histological slides are deposited in the herpetology collection of the Natural History Museum of Los Angeles County.

Data on the male *L. zonata* seasonal testicular cycle are presented in Table 1. Testicular histology was similar to that reported in the colubrid snakes, *Masticophis taeniatus* and *Pituophis melanoleucus*, by Goldberg and Parker (1975). In the regressed testes, seminiferous tubules contain spermatogonia and Sertoli cells. During recrudescence, there is renewal of spermatogenic cells characterized by spermatogonial divisions; primary spermatocytes, secondary spermatocytes and spermatids may be present. In spermiogenesis, metamorphosing spermatids and mature sperm are present.

Small sample sizes prevent a definitive analysis of the testicular cycle (Table 1). The major period of spermiogenesis (sperm formation) occurs in late-summer

Table 1. Monthly distribution of conditions in seasonal testicular cycle of *Lampropeltis zonata*. Values shown are the numbers of males exhibiting each of the three conditions of the testes.

Month	N	Regressed	Recrudescent	Spermiogenic
March	1	1	0	0
April	1	1	0	0
May	3	3	0	0
June	3	1	1	1
July	5	2	1	2
August	8*	0	2	6
September	2	0	0	2

* Includes two males from Santa Cruz County.

and may continue into autumn. One male was undergoing spermiogenesis in June, suggesting that sperm production may start as early as late spring in some males. The smallest male to undergo spermiogenesis measured 454 mm SVL. The presence of June–August males with recrudescent testes may indicate initiation of a new spermiogenic cycle. Testes of March–May males were regressed. The epididymis of a June male with regressed testes contained sperm. This suggests the *L. zonata* testicular cycle may be aestival (summer) and postnuptial (sensu Volsøe 1944; Saint Girons 1982) with spermiogenesis occurring in late summer to early autumn. Sperm are stored in the ductus deferens through winter; mating occurs in spring (Saint Girons 1982). This agrees with reports of *L. zonata* mating in spring (De Lisle et al. 1986; McGurty 1988).

Clutch sizes (number enlarged follicles) for *L. zonata* females are given in Table 2. In addition, museum records (LACM) indicate that one female, 523 mm SVL which was collected 10 July, laid 2 eggs on 14 July that hatched on 5–7 September. Neonates measured 183 mm and 188 mm SVL. This incubation period (53 days) was shorter than the 63 days reported for a *L. zonata* egg clutch to hatch by Perkins (1952). Another female (643 mm SVL) collected on 22 June, deposited 4 eggs on 2 August. Three of these eggs hatched (dates unknown). Neonates measured 150, 156 and 164 mm SVL. The above clutch sizes (2–6) are close to the range of 3–8 eggs reported for *L. zonata* by De Lisle et al. (1986) and Stebbins (1985) and 3–9 eggs given by Rossi and Rossi (1995). The smallest female with enlarged follicles measured 522 mm SVL.

Histological examination revealed early yolk deposition in one April female *L. zonata* (512 mm SVL). However, no yolk deposition was present in two other April females (539 and 608 mm SVL), in one May female (621 mm SVL), in one

Table 2. Data on clutch sizes (number enlarged follicles) from *Lampropeltis zonata* museum specimens.

Collection date	SVL (mm)	Clutch size	Follicle diameter (mm)
28 May	621	5	8–10
9 June	535	6	6–8
11 June	594	6	6–10
1 July	522	4	9–11

June female (512 mm SVL) or in one July female (465 mm SVL). Seven of twelve (58%) *L. zonata* females examined herein (from different years) were reproductively active. The presence of some apparently non-reproductive females during the breeding season may suggest that not all mature *L. zonata* females breed each year. Breeding by only part of a female population appears to be common in snakes. Seigel and Ford (1987) surveyed proportions of breeding females per year for 85 snake species and found proportions varied from 7% to 100%.

Lampropeltis zonata appears to have limited seasonal activity, secretive habits and a spotty distribution, resulting in relatively small numbers of this species in herpetology collections (Stebbins 1954). Additional study will be required before the reproductive biology of *L. zonata* can be clarified.

I thank Robert L. Bezy (Natural History Museum of Los Angeles County) and Sally Y. Shelton (San Diego Natural History Museum) for permission to examine snakes in the herpetology collections of their respective institutions. Leslie N. Ajimine assisted with histology.

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Appendix 1

Specimens examined by county from herpetology collections, Natural History Museum of Los Angeles County (LACM) and San Diego Natural History Museum (SDSNH). Los Angeles: LACM

2476; 2478; 20325; 20328; 20329; 20331; 20332; 20333; 20336; 20337; 115822; 115824–115826. SDSNH 2822; 4352–4353. Riverside: LACM 2481; 136938. San Bernadino: LACM 20340–20341; 20346; 102588–102590; 136939; 136942; 136943. SDSNH 4973; 43606. Orange: LACM 102585–102586. San Diego: SDSNH 4972; 8617; 11092; 20943; 46050; 48080; Santa Cruz: SDSNH 37823; 39282.

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